SCIENTIFIC STUDY OF UNIDENTIFIED FLYING OBJECTS

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Chapter 2

Processes of Perception, Conception, and Reporting

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1. Introduction

The preceding chapter outlined the sequence of events, physical, physiological, and psychological, by which perception of a phenomenon is combined with previous conceptions. In this chapter we will review some evidence on how this proceeds in fact, and on how the conceptions, sometimes after significant interpretation, produce a report.

The question underlying this discussion is this: Are misinterpretation and misreporting sufficiently common as to make credible the assertion that the entire UFO phenomenon, or at least the residual of unidentified cases, is the result of these processes (plus deliberate hoaxes)? The data show that this assertion is indeed credible, although, of course, we cannot prove that this accounts for the unidentified objects.

2. Perception: Objects and Phenomena in the Atmosphere

In practice, it has proven impossible and potentially misleading to try to tabulate all of the possible causes of UFO perception. There are simply too many. The very point that is emphasized by case after case is the incredible variety of circumstances that may cause one to perceive an apparition of high strangeness and conceive of it as an UFO, or even more specifically as a "flying saucer."

Minnaert (1954), Menzel (1953), and Menzel and Boyd (1963) have described in detail many objects and phenomena that are unfamiliar to most persons. We need not repeat their description here. However, simply to illustrate the variety of causes that can and have produced UFO reports, Table 1 briefly lists some of the possibilities.

We can be virtually certain that all of the causes in Table 1 have, at one time or another, produced perceptions that could not be identified by the observer. It is perhaps not surprising, therefore, that about 3,000,000 out of 125,000,000 adult civilian Americans have perceived

Table 1

Examples of UFO-Related Objects and Phenomena

Meteorological

Subsun	Gulfstream aircraft (Case 54)
Lenticular clouds	Cf. Section III, Chapter 3
Noctilucent clouds	"Glowing" clouds, often in peculiar shapes
Mirages	Examples cited by Menzel (1953), Menzel and Boyd (1963)
Sundog	
"Dust devils", etc.	Debris thrown into air without apparent support.
St. Elmo's fire	Cf. Section VI, Chapter 7
Ball lightning	

Astronomical

Meteors, fireballs	Cf. discussion of 1913 fireball, this chapter
Satellite reentries	Cf. discussion of Zond IV, this chapter
Aurora	
Venus, other planets	

Experimental and Technological

"Skyhook" balloons	Responsible for Mantell tragedy (Menzel and Boyd, 1963)
Other balloons	
Test aircraft	Certain, little-flown types have been disk-shaped
Rocket launches	Rockets & contrails have generated UFO reports
High-alt. projectiles	Have been used in flare and wind-study experiments (Cf. New Mexico aircraft (Case 55)
Bomb tests	Fort Belvoir, Va. (Case 50)
Contrails	
Refueling	Coarsegold, Calif. (Case 28)
Searchlight reflections	

Table 1 (cont'd)

Aircraft reflections	Great Falls, Mont. (Case 47)
Aircraft afterburner	
Aircraft seen at unusual angles	
Aircraft landing lights	
Flare experiments	

Physiological and Psychological

Autokinesis	Perceived motion of objects known to be stationary
"Autostasis"	Perceived stopping of objects known to be moving
Entoptic effects	Generated within the eyeball
Motes on the cornea	Perceived as spots
Hallucination	
"Airship effect"	Perceived connection of separate sources (cf. this chapter)
"Excitedness effect"	Selection effect on reports (cf. this chapter)

Industrial Effects

Detergent foam	

Biological

Angel hair	
Airborn debris (e.g. milkweed)	Camarillo, Calif. (Case 58)
Birds, flocks of birds	Tremonton, Utah (Case 49)
Swarms of insects	
Luminous fungi on birds	
Fireflies	

Miscellaneous

Hot-air balloons	UFO reports generated by toy balloons using candles to create hot air (Boulder, Colo., Case 18)

Table 1 (cont'd)

Kites	
Reflections off windows	Witness interprets reflection as object outside window
Material fixed or moving on window	As above
Deliberate hoaxes	

phenomena that they classify as "Unidentified Flying Objects" (See Section III, Chapter 8). The question is whether a few of these reports are extraordinary.

Table 1 raises a problem for the UFO investigator: in a given case, how unusual may a phenomenon be to be cited as explanation? Certain investigators have been widely criticized for constructing elaborate conditions to explain (or explain away) UFO reports. One should be guided by "Occam's Razor": an explanation becomes less credible as the number of *ad hoc* assumptions increases. Table 1 is not a list by which every case can be explained, but it does suggest that even without alien spaceships and undiscovered physical phenomena, many strange things will be perceived.

As an example of the complexities of just one class of objects, which has been inadequately studied both within and outside the context of UFOs, consider meteoroidal bolides. Bolides have produced exceedingly spectacular and unusual displays, but it is not widely recognized that they probably include a variety of objects. There are cometary debris, thought to be fragile and with a high volatile content, leading to fragmentation in the atmosphere. Many of these, having drifted in from the outskirts of the solar system have a very high velocity. Asteroidal fragments, thought to be represented by the stony and iron meteorites, enter the atmosphere at intermediate velocities and may have a different mass distribution. Least known of all, there may be a group of low velocity objects that are debris blown off the moon by impacts or in some other way captured in the earth-moon system. There may even be other unknown sources of cosmic debris.

The slow bolides (entry speed ≈ escape velocity) are of particular relevance and interest because of the part that the epidemic of slow, green fireballs played in the development of the UFO problem in 1948-49 (Ruppelt 1956; Menzel and Boyd, 1963), and because of the scattered reports in the astronomical literature of majestic slow fireballs (Chant, 1913; discussed below). As an example of the diverse data bearing on the UFO problem, consider the possibility of observing fragments blown off the

moon. It is believed that interplanetary meteoroids striking the moon dislodge material amounting to some hundreds of times their own mass (Gault, 1964). Material totaling roughly the initial projectile's mass may escape the moon's gravitational field, probably in the form of particles much smaller than the original projectile (Gault, 1964). Ordinary meteors of mass 10^4 gm are of magnitude about -10 (Vedder, 1966), and we may infer that a fragment of such mass from the moon would produce a spectacular display as it enters the earth's atmosphere. That is, lunar-impacting projectiles of mass of the order 10^6 to 10^8 gm could be expected to throw out fragments that, entering the earth's atmosphere, could produce spectacular, slow fireballs. How often do such *lunar* impacts occur? Meteor fluxes have been thoroughly reviewed by Vedder (1966) and for the mass range given, the rate of lunar impacts is estimated to be in the range 10 to 10^{-1} per year. It is expected that many circumlunar particles would ultimately decay into the earth's atmosphere so that we may predict that every few decades, or even more frequently, spectacular slow fireballs of lunar origin should occur, and that groupings of these objects would appear over periods of weeks, since clusters of ejecta are thrown out by each lunar impact, to decay at different rates.

This illustration is chosen because the predicted characteristics match those of the "green fireball episode" and suggest that lunar debris may, indeed, be the explanation of those unusual bolides.

It is important to note that we have not yet even considered the possibility that any of the common or unusual causes in Table 1 may be badly reported, so that an investigator may become hopelessly confused.

Whoever believes that the UFO phenomenon represents revolutionary and fantastic events must take full account of the facts that (1) UFOs by definition include all phenomena unknown to the observer; (2) such phenomena are present in effectively infinite variety, so that even widely experienced investigators, not to mention inexperienced witnesses, may be unaware of them; and (3) such phenomena, even if accurately perceived, may be badly interpreted and reported by the observer.

3. Conception : The Re-entry of Zond IV Debris

It is remarkably common for astronomers, when queried about UFOs, to cite the misconceptions that accompany reports of meteors. Most astronomers have talked to witnesses who believe a prominent meteor landed "just behind the barn" or "just over the hill;" thus, they stress the limitations of verbal reports from average observers.

Project Blue Book has supplied us with exceptionally good data to illuminate this problem. On 3 March 1968 the news agency of the Soviet Union announced that the spacecraft "Zond IV" had been placed in a low "parking orbit" around the earth and would soon be launched into "outlying regions of near-earth space" (Sullivan, 1968) The mission was unsuccessful. At about 9:45 p.m. EST on 3 March, hundreds of American observers near a line from Kentucky to Pennsylvania saw a majestic procession of fiery objects with sparkling golden orange tails move across their sky. The spacecraft was disintegrating upon re-entry. Most observers saw two or three main pieces, while observers near the end of the path saw more. These objects were soon identified by NORAD as pieces of the Zond IV probe or its rocket booster and this identification was finally confirmed 1 July 1968 (Sullivan, 1968).

This case put us in the rare and fortunate position of knowing exactly what was involved even before we began to investigate the many UFO reports that were generated.

In brief, many of these reports were quite good, but there is an admixture of spurious elements that are astonishingly familiar to students of the "flying saucer" literature. The latter vividly illustrate the problem of conception and interpretation, and shed light on the entire UFO phenomenon.

Consider the conceptions that may be generated if one perceives three bright point sources moving across the night sky at constant angular separation of, say, 5°. The most objective observer may report as directly as possible the percept: three point sources moving with a constant angular separation. But this is just one end of a spectrum. A less objective observer and, from our Zond IV data, a demonstrably

more typical one may introduce subtle elements of interpretation. He may report three point sources *flying* with constant angular separation, or three *lights flying* with constant angular separation, or three *lights flying in formation*. These changes in conception may be subtle, but when the observer *reports* his conception to a second party, they may produce vividly different conceptions (especially if the second party is inclined to believe "flying saucers" exist). Further toward the other end of the spectrum, but less typical than the above examples, a highly unobjective observer may introduce totally spurious elements. He may report three *craft flying in formation*. He may, for example, conceive the idea that the three point sources are connected, since they maintain a constant pattern. He may even imagine a dark elongated form connecting them so that they become *lights on a cigar-shaped object*, or even *windows on a cigar-shaped object*.

This spectrum of the conceptions of observers is not based on mere theorizing. It is directly derived from the Zond IV observations.

Quantitative analysis of the observations is somewhat confused by their heterogeneity. The file supplied by Project Blue Book contains reports ranging from very complete accounts on official Air Force report forms to fragmentary records of telephone reports. In all, there are some 78 reports, but only about 30 detailed letters or forms attempting to give a complete description are appropriate for analysis. There are only 12 Air Force report forms from which one can study the variations in response to specific questions; e.g. angular size, velocity, etc.

Study of the file, some 30 complete reports produced counts of certain conceptions indicated in Table 2, listed in order of decreasing frequency.

The following remarks apply to the items in Table 2. Item (1) shows that virtually all the reports that made reference to sound correctly agree that there was none. One witness (item 16) reported sound like a piece of tin hurtling through the air. We can be certain this is in error; this conception must have resulted from an unrelated noise or a hallucination due to a belief that there *ought* to have been a sound. Items (2) and (14) are somewhat misleading semantic errors. A better

Table 2

Selected Conceptions Generated by Zond IV Re-entry*

Conception	No. of Reports
1. Report absence of any sound	20
2. Report "formation"	17**
3. Estimate altitude or distance < 20 mi.	13**
4. Suggest phenomenon may be meteor(ite) or satellite re-entry	12
5. Report straight, uniform motion	12
6. Indicate individual sources were of angular size $\gtrsim 7'$	10**
7. Report rocket- or cigar-shape, or "saucer" shape	7**
8. Report curvature or change of direction or motion	6**
9. Estimate altitude or distance at < 10,000 ft.	5**
10. Report cigar-shape or rocket-shape	5**
11. Report "fuzzy" outline	4
12. Report "windows"	3**
13. Describe lights (implying lights *on* something)	2**
14. Refer to exhaust	2**
15. Report sharp, well defined outline	2**
16. Report noise	1**
17. Report reaction of animal	1**
18. Report vertical descent	1**

*Based in effect, on about 30 relatively complete reports out of a total file of 78.

**Conceptions that are to greater or lesser degree erroneous.

choice of word than "formation" would have been "pattern" or "constellation." "Formation" and "exhaust" imply guided vehicles. One observer even described one object as "pursuing" another; it "looked as if it was [sic] making an attempt to shoot the other one down." (3) and (9): As is usually the case with meteor reports, the object was conceived of as being much closer than in fact. This presumably results from the average observer's unfamiliarity with the concept of watching objects a hundred miles away. (4): A number of observers correctly considered meteoritic phenomena. A smaller number flatly identified the apparition as a re-entry of some sort and a few even indicated that they gave it scarcely a thought until they later heard of the excitement generated through radio, and newspapers! (5) and (8): Most observers described an essentially linear path, but a smaller number reported changes in direction. A few even ruled out a meteoritic phenomenon on this basis. Most of the reports of change in direction must be subjective, perhaps an autokinesis effect, but some are thought to result from observers own motion in vehicles. (7): This includes all descriptions typical of "flying saucers," and (6), (7), and (10) together indicate a strong tendency to conceive of a *shape* even though the phenomenon involved virtual point sources. Most observers indicated that the fragments were about 3-4 min. of arc in diameter, just within the resolving power of the normal human eye. Reports of a "cigar-shape" apparently stem from a subjective tendency to connect the string of sources and from popularization of this concept in the UFO literature. This important phenomenon I will call the "airship effect;" it is demonstrably present even in reports as far back as 1913, and in Cases 34 and 37. Items (11) and (15), which seem to indicate merely the inadequacy of the report form's question (The edges of the object were: Fuzzy or blurred? Sharply outlined?) in the case of a near-point source with an ill-defined tail. Items (12) and (13) illustrate serious misconceptions, apparently due to unconscious *assumption* that there was a vehicle. Item (17) refers to a report that a dog was noted to become upset and to huddle, whimpering, between two trash cans. According to her own testimony, the witness, was quite excited and the dog presumably detected this.

The Air Force report forms comprise a smaller set of more homogeneous data, since the questions are standardized. A range of conceptions are illustrated by the 12 report forms plus 5 highly detailed accounts, and are summarized in Table 2. The angular size, a relatively objective measurement, is fairly consistently estimated. The size, distance, and velocity estimates are hopelessly misconceived, as we have already seen, since the observers had no objective way of determining any of these (without realizing that a re-entry was involved). The estimates appear to be influenced by prior conceptions of and familiarity with airplanes. Typical errors exceed a factor of ten. Only four of the 12 respondents correctly noted that they could not estimate the speed. Of 17 observers, four chose to describe a "formation," and two, "windows."

An effect important to the UFO problem is demonstrated by the records: the excited observers who thought they had witnessed a very strange phenomenon produced the most detailed, longest, and most misconceived reports, but those who by virtue of experience most nearly recognized the nature of the phenomenon became the least excited and produced the briefest reports. The "*excitedness effect*" has an important bearing on the UFO problem. It is a selection effect by which the least accurate reports are made more prominent (since the observer becomes highly motivated to make a report), while the most accurate reports may not be recorded. In the case of Zond IV the two most lengthy unsolicited reports described the apparition as a cigar-shaped craft with a row of lighted windows and a fiery tail, while the correct identifications as a re-entry were short, in some cases recovered only by later solicitation of reports.

In summary, we conclude that all of the following factors demonstrably confuse reports of unidentified phenomena and make subsequent investigation difficult: (1) Objects are conceived of in terms of familiar concepts, such as aircraft. This produces misconceptions of distance, speed, shape, etc. (2) At least during the last decade conceptions have been heavily influenced by the "flying saucer" concept in movies, TV, and periodicals. Reports of "saucer-shape," "cigar-shape," and physiological reaction are probably a consequence. (3) Due to the nature of certain cases,

certain questions on prepared questionnaires or report forms become ambiguous or meaningless. (4) The "excitedness effect" biases reports toward those containing more exotic conceptions. (5) The "airship effect" causes some observers to conceive of a shape surrounding light sources.

It is scarcely short of amazing, and certainly suggestive, that the seemingly straightforward Zond IV incident produced a high percentage of the very phenomena that have puzzled students of the UFO problem. Table 3 lists a selection of such reports. We have, in fact, reports of (1) a cigar-shaped object with windows and a flaming exhaust, (2) a vehicle or craft that passed low overhead in utter silence, (3) psycho-physiological response of dread, or in another case, an urge to sleep, and, (4) abnormal behavior of a nearby animal. To the extent that the argument for "flying saucers" rests on the strangeness of such observations, it is thereby weakened.

Of course, the important question in a case such as the Zond IV re-entry is not the quality of the worst observations, but rather whether the observations taken together did define and clarify the phenomenon. My own judgment is that, together, the reports *would* suggest a re-entry to anyone who was familiar with such a phenomenon. This results primarily from the vividness of this particular case, and the attendant diagnostic features: a bright bolide slowly disintegrating into many fragments, each attended by a train. Nonetheless, it must be said that only a fraction, about a quarter, of the reports point directly in this direction while about another quarter are misleading and the remainder insufficiently detailed to be diagnostic. A reporter or investigator coming upon the case in innocence would be hardput to distinguish the good from the bad reports.

Table 3 demonstrates that a large part of the UFO problem is a semantic one. One may point out that an accurate reconstruction of this incident would have been, after all, possible from the bulk of reports; but to generate a UFO case we need only (say) one to four

Table 3

Selected Descriptive Comments on Zond IV Re-entry

Nature of the object:

"[I heard on] news . . . it was space junk. Never. It came down then went forward in perfect formation. So how can gravity be defied?"

"Suggestions: 1. Cylinder type rocket with two thrust rocket engines and one rocket engine in front for guiding purposes. 2. Meteor broken into three main parts. 3. Space or aeronautical craft."

"Observer does not think the objects were either satellite debris or meteors because they had a flat trajectory."

"Didn't attach much importance to the object because I thought it was a re-entry."

"Thought it looked like something burning up in space . . . . Thought it looked like a turn-in."

"I wasn't aware that I had seen anything unusual until the local TV newscast . . . advised of many other sightings of same for miles around."

"Neither I nor my fiancee sighted any connecting lines [among the bright sources]. If there were connecting lines, it would have formed the fuselage of a B-52 only about thirty to forty times bigger."

"Could not see actual object."

Appearance of object:

"All . . . observers saw a long jet airplane-looking vehicle without any wings. It was on fire both in front and behind. All observers also saw many windows . . . . If there had been anybody in the UFO near the windows I would have seen them."

"It was shaped like a fat cigar, in my estimation . . . . It appeared to have rather square shaped windows along the side that was facing us . . . . It appeared to me that the fuselage was constructed of many pieced or flat sheets . . . with a 'riveted together look' . . . . The many 'windows' seemed to be lit up from the inside."

[It could be compared to] "ordinary saucer inverted without protrusion on top; elongated a little more than a saucer. Protrusion on bottom midline and about 50% of bottom so covered."

Table 3 (cont'd)

"No flame was visible but . . . quantity of golden sparks . . . . In my opinion it was a solid rocket type vehicle with three lights or three oval saucer type vehicles."

"Object had red and blue lights."

"Observed an unidentified object . . . . It was long and narrow with a light in front and in back there was a streaming tail . . . . The object was dark black, trail was yellow gold."

"Fiery orange, long and narrow."

"Definite disk shaped."

"It was like two disk-shaped lights in some planned position."

"Tail appeared as metallic sparks."

"Formation flight:"

"They flew in a perfect military formation."

When asked if they could be meteorites, [witness] replied, "It would be the first time I ever saw meteorites fly formation."

"It appeared as if one object was in pursuit of the other. One object seemed to be traveling at a higher or greater speed than the one pursuing it. The pursuing object . . . looked as if it was making an attempt to shoot the other one down."

Distance and dimensions:

"It was at about treetop level and was seen very, very clearly, just a few yards away."

A pilot "estimated each [tail] was about 0.5 mile in length."

"We saw two orange lights tailing [sic] about two yards apart."

Observer "felt that it would have hit in the wooded area south of (her city)."

Response and reaction:

"I really wanted to see a UFO. I remember saying aloud . . . 'This is no natural phenomenon. It's really UFOs, I . . . made an attempt to

Table 3 (cont'd)

communicate with them. I had a flashlight . . . [and] signaled . . . in Morse code . . . . No visible response elicited . . . . After I came into the house I had an overpowering drive to sleep . . . . My dog . . . went over between the two trash cans . . . and whimpered and lay on the drive between the cans like she was frightened to death . . . . High frequency sound inaudible to us?"

"Frightened my eleven year old son, who was out with his telescope."

Hearsay:

"I heard there were [72] grass fires in this area on the day following this sighting. I would think there might be a possible connection."

witnesses to agree on and express misleading conceptions and other witnesses to be silent or (more commonly) non-existent.

4. Conception: Re-entry of Titan 3 C-4 Debris

An incident less widely observed than the Zond IV re-entry gave the writer an opportunity to compare his personal observation of the re-entry of satellite debris with verbal reports solicited from his community. The results are similar to those of the case described above.

On 28 September 1967, at 9:53 MDST I noticed from Tucson, a bright, orange-red stellar object drifting across the northern sky toward the northeast at a rate of about 40' of arc per sec. Though initially of about zero magnitude, it suddenly disappeared, giving the impression of a jet plane cutting off its afterburner. However, the object suddenly reappeared, then repeated the performance several times. During the last few degrees of the trail, some 5°-10° above the horizon, there appeared to be a disintegration into several barely resolved fragments. A second or two later, another object appeared and followed the first one down to the last 4° of the trail. Meanwhile, a faint milky-white train which had been left by the first object brightened for about 10 sec., then faded, twisted, and broke up in a period of about 6 min.

The tell-tale features of a satellite re-entry were present: the object was too slow for a meteor, had the brightness fluctuations and color of a burning object, fragmented, moved eastward and left a train that was distorted by high altitude winds. A later check through the Colorado project indicated that re-entry of certain fragments of Titan 3 C-4 satellite 1965-82KD, had been estimated to occur at about 6:00 a.m., MDST, on 29 September 1967 (see also King-Hele and Quinn, 1966). Earlier, the satellite had exploded in orbit, and the fragments were spread out along the orbit, so that sporadic decays near the predicted time were not unexpected; the observation of a second fragment a few

seconds (some tens of miles) behind the first was consistent with this. Hence, the identification is regarded as virtually certain.

Rarely does the investigator himself have an opportunity to see the "UFO" being described. In order to take advantage of this opportunity to compare my own observations to the conceptions and semantics generated, I solicited observations through a local newspaper.

Fifteen reports were received from the Tucson area by telephone. The reports ranged from quite accurate to quite misleading. The most misleading of the 15 was from an articulate woman who was to all appearances an astute observer. She clearly reported that the object fell *between her and some mountains* a few miles away, appearing in front of (south of) the mountains and below their crests. (This conflicts with other reports of observers located north and west of the mountains, as well as the known identity of the object.) Other misconceptions reported included: (1) red and green flashing or rotating light (possibly confusing the object with an aircraft that was near the witness?); (2) much bigger than a star, could see a round shape; (3) motion toward the west (confusion with another object?); (4) "Looked like it was coming down right at me. It scared me. It was like it was right over me - like a fat airplane - with a big window." This is a repetition of the "airship effect" in which the observer conceives of a light as an aperture in a black, unseen, larger form.

The writer had concluded (before the Zond IV results were available) that roughly a quarter of the reports were accurate and acticulate enough to be definitive, roughly a quarter contained seriously misleading elements, and the rest were sufficiently inarticulate or whimsical to be of no great value (It was "real red, like, you know, and pretty . . . It turned [sic] a beautiful white streak . . ."). A report made by an investigator arriving later would have depended on which conceptions he heard or adopted. The right selection would have cleared up any problem; the wrong one might have created a seemingly inexplicable and possibly celebrated UFO report.

5. Conception: The Great Fireball of 9 February 1913

C. A. Chant (1913a), in a 71-page report, gives a detailed account of the spectacular meteoric display of 9 February 1913. The series of disintegrating bolides passed from Saskatchewan ESE over the Great Lakes and over the New Jersey coast. Several "waves" of clustered objects were seen, noise was heard at least 50 mi. from the sub-bolide point, and ground shocks were reported. Other remarkable sporadic meteors were seen in various scattered locations around the world for a period of some days. Chant deduced that the height of the path, which followed the earth's curvature, was about 26 mi. and that the geocentric velocity was in the range 5-10 mi/sec. M. Davidson (1913) reanalyzed Chant's data, plus observations from Bermuda, and concluded that the object had a height of some 46 mi. over Ontario, and Chant (1913b) subsequently inferred that they reached perigee over Ontario, but were not destroyed, moving out into a new orbit when seen from Bermuda.

The phenomenon appeared rather like the Zond IV re-entry. It is well-described in the "extended extracts" from letters published by Chant. Clusters of stellar-like objects passed overhead, with tails several degrees long and accompanied by smaller, fainter objects. It is a subjective judgment, possibly influenced by some editing of the letters by Chant, that the 1913 reports are on the whole more objective than those of this decade. There are probably two reasons for this : (1) In 1913 the demarcation between "educated" persons, from whom Chant was likely to receive letters, and "uneducated persons," was greater. (2) In 1913, there was no widely known conception (i.e. pre-conception of mysterious saucer-shaped aircraft or spaceship (although several reports refer to the object as an airship). Further, the 1913 reports (as published) tend to be more descriptive; the word "meteor" is used in a non-generic sense simply to mean a bright object passing across the sky. There is little attempt among the correspondents to infer what the objects were.

Chant himself indicates that the reports varied in quality due to the process of conception and interpretation: "The reader . . . will . . . see that intelligent people can differ widely in describing a phenomenon, and will be able to appreciate the difficulty I have had in discriminating between very discordant observations." He presents reports of nearly 150 witnesses.

The "airship effect" is clearly present. Consider these reports: (1) "The series of lights travelled in unison and so horizontal that I could think only of a giant flying machine. The lights were at different points, one in front, one further back, and a rear light, then a succession of small lights in the tail." (2) "They . . . did not seem to be falling as meteors usually do, but kept a straight course . . . above the horizon. Our first impression was that a fleet of illuminated airships of monstrous size [was] passing. The incandescent fragments themselves formed what to us looked like the illuminations while the tails seemed to make the frame of the machine. They looked like ships travelling in company." (3) "The meteor resembled a large aeroplane or dirigible, with two tiers of lights strung along the sides." (4) The witnesses "reported that they had seen an airship going east. The heavens were brilliantly illuminated, and with the passage of the meteors a shower of stones was seen to fall." (This last element is not mentioned elsewhere and appears to be spurious.) (5) "I took it for an aeroplane with both headlights lit, and as it came nearer the sparks falling behind it made it appear still more like one. However after a minute or a minute and a half I could see it was a meteor . . . . It was very low, apparently just above the hills. (6) "My brother shouted to me, 'An airship! And I said, 'Mrs. M---'s chimney is on fire! It looked that near . . . . To the eye they were little above the housetops." (7) " . . . a voice from a group of men was heard to say: 'Oh, boys, I'll tell you what it is - an aeroplane race.'"

We have already noted in the Zond IV case that the angular size, a relatively objective estimate, was consistently measured. In this

case the description of the noise is remarkably consistent, perhaps because of the ready availability of a charming simile. Here are five consecutive descriptions of the noise: (1) " . . . a heavy noise like a clap of thunder at a distance;" (2) " . . . a low rumble which at first made me think it was a buggy going along the road from church;" (3) " . . . like thunder, loud at first and rumbling every two or three seconds;" (4) " . . . like a horse and rig going over a bridge;" (5) " . . . like a wagon passing over a rough road."

There was more difficulty with conceptions such as angular elevation and distance. As usual, the latter was grossly underestimated. (1) " . . . midway between the horizon and the sky . . ." (2) " . . . midway between the earth and the sky . . ." (3) They travelled no faster than a crow flies." (4) " . . . never have I [seen] so many heavenly bodies moving at one time, or any moving so slowly or in so low an altitude." (5) "They looked to pass about one mile south and at an elevation of about 300 feet." (6) " . . . I saw [it] for about half a minute. In that time it seemed to go about 150 yards." (7) "The position in the sky of the first one seemed very low, so low that at first I thought it was a rocket." (Skyrockets, of the fireworks type, were a common analogue).

Many more reports could be cited, illustrating comparison with familiar objects (kites, funnels, ships in formation), in some cases misleading, even though the reports taken together present a relatively clear picture. We again can conclude that a substantial number of misleading reports will be introduced in observations of unusual phenomena.

6. Additional Remarks on Percepts and Concepts

The "airship effect" and "excitedness effect" apply to the Eastern Airlines case of 1948 (better known as the Chiles-Whitted case). This will serve as an example of the difficulties of establishing any concrete evidence for "flying saucers" when one is forced to distinguish percepts and concepts of a few witnesses in older cases.

Briefly, pilot Chiles and co-pilot Whitted reported flashing by them in a few seconds a "wingless aircraft with no fins or protruding surfaces, [which] was cigar-shaped, about 100 ft. long, and about twice the diameter of a B-29 Superfortress. It seemed to have two rows of windows through which glowed a very bright light, brilliant as a magnesium flare. An intense dark-blue glow like a blue fluorescent factory light shown at the bottom along the entire length, and red-orange flames shot out from the rear to a distance of some fifty feet" (Menzel, 1963).

This case has been one of the mainstays in the arguments for "flying saucers" and NICAP has described it as the "classic" cigar-shaped object (Hall, 1964). Hynek, as consultant to the Air Force, and Menzel and Boyd account for it as a fireball (Menzel, 1963).

The present discussion provides definitive evidence that fireballs can be described in *just* the way reported by Chiles and Whitted. The investigator is faced with the perfectly conceivable possibility that Chiles and Whitted, suffering from the "airship effect," became excited and reported a misconception - a cigar-shaped object with windows and flames - just as a fraction of witnesses to spectacular fireballs are now known to do.

A second example from my own experience illustrates the difficulties of transforming perceptions into conceptions (and explanations). During the course of the Colorado project investigation, I was sitting in the left side of an airliner, just behind the wing. As I looked out over patchy clouds, I saw an object apparently passing us in the distance, flying the other way. It came out from under our wing, not far below the horizon, and drifted slowly behind us until, because of the window geometry, I could no longer see far enough behind to observe it. It moved like a distant airliner, but was a grey, ill-defined disk, with major axis about a third of the apparent size of the moon. It was darker than the clouds, but lighter than the ground. It appeared to be a disk-shaped, nebulous "aircraft," flying smoothly in an orientation parallel to the ground.

I was sufficiently shaken by this to pull out some paper and begin making copious notes. During this operation I glanced out again and this time saw clearly a distant airliner, slightly above the horizon this time, but moving in the same way. There was no question that *this* was an airliner, for in spite of its having the same angular size as the disk, I could clearly see its wings and tail. Just then, the pilot banked to the right, raising the left wing, and suddenly the distant plane became a grey, nebulous disk. It had passed behind the distorting exhaust stream of the jet engine, which was suspended and obscured under the wing. The first disk, or plane, had flown directly behind this stream, whose presence had slipped my mind.

In summary, an investigator of UFOs is in effect asking for all the records of strange things seen, and he must be sober in recognizing the tremendous variety of sources of distortion and misconception. Each case of misconception may involve its own processes of error, but perhaps common to all such cases is an easy tendency to "fix" on an early conception of a percept, by a process that is analogous to that of the "staircase" optical illusion in which one conceives of the staircase as being seen either from "above" or "below". Another example is the common difficulty in looking at aerial photographs. One may conceive of the relief as being seen either "positive" or "negative." Once the conception occurs it is difficult to dispel it. If you see a star at night from an airplane but conceive of it as an object pacing the aircraft at only 300 yd. distance, it is easy to retain this conception. As R. V. Jones (1968) has pointed out (reviewing his wartime intelligence investigative experience in the context of the UFO problem), "witnesses were generally right when they said that *something* had happened at a particular place, although they could be wildly wrong about *what* had happened." (WKH emphasis).

7. Reporting

"Reporting" means the process of transmission of the observation - from the observer to a journalist, Air Force investigator, the police,

etc., and from there to the public. Reporting, we have found, is one of the most crucial factors in the UFO problem. My own conclusion has been that one must not form a judgment of any case from the popular literature.

Suppose, for example, that the pilot of my airliner had not banked the plane wing, and I had not learned the explanation of the grey, nebulous, elliptical object. I would have submitted my report, not of a "flying saucer," but of an object I could not identify. Assuming that the story got out, it is highly probable that because of its clear news value ("COLORADO PROJECT INVESTIGATOR SEES DISK"), it would have been publicized before anyone established that the jet exhaust had produced the phenomenon. Such a story, brought to public attention by newspapers and magazines, would stir more pressure on public officials and contribute to the illogical but widesperad feeling that where there is so much smoke there must be *some* fire. A later solution would not be so widely publicized.

Ruppelt (1956) discusses another example that occurred in actual fact. The famous Maury Island Hoax, which even today stirs interest, was widely publicized. The story was sensational, in that it involved alleged fragments of a saucer that had been seen to explode. Two Air Force investigators on the case were killed in an accidental plane crash. The case was later clearly identified as a hoax. Ruppelt remarks,

> The majority of writers of saucer lore have played this sighting to the hilt, pointing out as their main premise . . . that the story must be true because the government never openly exposed or prosecuted either of the two hoaxers. . . . the government had thought seriously of prosecuting the men, (but) it was decided, after talking to the two men, that the hoax was a harmless joke that had mushroomed. . . . By the time the facts were released they were yesterday's news. And *nothing is deader than yesterday's news*. (WKH emphasis).

Many writers in our culture, from fanatics and hypocrites to sincere reporters, are not, after all, committed to complete investigation and understanding of the subject, but to telling and selling a good story. Unfortunately there is a selection effect: if a "flying saucer" story is investigated *too* completely, and is found to be a misperception or a hoax, its interest and sales value are reduced.

Examples of journalists' distortion and slanting, conscious or unconscious, abound: misinformed amateurs quoted as authorities, repetition of hearsay evidence, and naive selection of data are examples of such dubious reporting. The UFO literature is full of the following sort of ill-advised criticism of non-believers: Edwards (1966) describes a case in which a world famous astronomer and authority on galactic structure, and two colleagues, reported that they had seen a "circular, luminous, orange-colored" light pass overhead too slowly to be a meteor. Noting that on the following day the Air Force, rechecking their files, found that the case was explained by two Vampire jets and a jet trainer on a routine training flight at 20,000 ft., Edwards then concludes with the remark, "If a professional astronomer really were incapable of telling *one* circular object from *three* jet planes at 20,000 feet, how reliable would his work be regarding an object 40 million miles away?" Aside from the facts that the "explanation" was not the astronomer's responsibility and that the latter figure misrepresents the scale of that astronomer's work by a factor of a billion, this concluding statement certainly shed no real light on the UFO problem, but rather creates a state of mind that may aid acceptance of the author's later remarks.

Jones (1968) illustrates well the problem of forming a reliable judgment from diverse reports of individuals on a single phenomenon. During the war, a British and an American physicist had the task of establishing from sailors' reports the German pattern of mine-laying at sea. One of them went on a field trip and discovered that reported ranges and bearings were unreliable; only the question of whether the mine was to the port or starboard was reliably answered. With this

discovery, he solved the problem while his counterpart became bogged in a mire of meaningless data. The point is that by actual field interviews one may get some idea of what happened, but under no circumstances, simply because a witness says (or is reported to have said) that he saw a cigar-shaped object, should one assume that a cigar-shaped object was really there

This well known rule applies in many other fields of investigation. Jones states: "I have made this discursion into some of my war experiences because it is relevant to the flying saucer story in that it illustrates the difficulty of establishing the truth from eyewitness reports, particularly when events have been witnessed under stress. I do not, of course, conclude that eyewitness reports must be discarded; on the contrary, excluding hoaxers and liars, most witnesses have genuinely seen something, although it may be difficult to decide from their descriptions what they really had seen."

There is still another problem: even if reliable reports are prepared, communication among investigators is so poor that the reports may not be read. Scientific journals have rejected careful analyses of UFO cases (apparently in fear of initiating fruitless controversy) in spite of earlier criticism (in the journals' own pages!) that the problem is not discussed in the scientific literature. Even at the most responsible levels, communication is poor. The House Committee on Science and Astronautics, in its 29 July 1968 hearings, received accounts of allegedly mysterious cases that already were among the best-explained of those studied by the Colorado UFO Project.

In order finally to demonstrate the very poor manner in which the UFO problem has been presented in the past, primarily in the popular literature, condider two imaginary accounts that could be written of the Zond IV re-entry, one by a sensationalizing, but perhaps sincere reporter, and one by a more sober investigator. Of course each reporter can back up his story with taped interviews and sketches.

A fantastic cigar-shaped object that entered the earth's atmosphere from space on 3 March 1968	Although there was some preliminary uncertainty in Air Force circles as to the

is unidentified. Although some Air Force officials attempted to pass it off as a satellite re-entry, exemination of the *official Air Force* papers indicates a reluctance to identify it with any known spacecraft.

The absurdity of the satellite explanation is proved by the reports of the witnesses who got the best look at the object. Witness after witness described the object as cigar-shaped, with a row or rows of windows and a flaming exhaust. Several others mentioned saucer-shaped lights visible as the craft flew overhead. Many observers, who apparently did not get such a good look at the mysterious craft, merely described a strange formation of lights.

There is little doubt that the craft came from space. The probability that it was under powered flight is raised not only by the exhaust but also by several observers who saw it change direction.

This event, witnessed by hundreds, in many states provides one of the best proofs yet that some kind of strange airships have invaded our atmosphere.

nature of the bolide of 3 March 1968, after several days study of the reports it became clear that the event was a satellite re-entry. This was confirmed some months later.

While the re-entry was confirmed by the bulk of the actual observations, it was badly misinterpreted by several excited witnesses, who wrote the longest reports and described the object as cigar-shaped. There was a tendency for some observers to interpret the string of disintetrating meteors as windows in a dark craft. Still others interpreted the yellowish tails of the objects as exhausts. Such misconceptions were widely scattered but in the minority.

Entering the atmosphere, the satellite grew incandescent and began to disintegrate into dozens of pieces, each moving at its own speed because of drag. Autokinesis effects were not uncommon among the ground observers, as the objects appeared as slowly moving light sources in the dark sky.

8. Reports: The Credible Number of "Flying Saucers"

Most readers of this report will perhaps be convinced that alien spaceships or some other unknown phenomena can be involved in only a very small percentage of all UFO reports or perhaps in none. Yet there is a curious tendency on the part of many students of the problem to imply that the sheer number of reports somehow proves that there must be some physical reality involved. For example, J. E. McDonald (1968) argues before the House Committee on Science and Astronautics, in a one-paragraph statement on witness credibility: " . . . It seems tedious to enlarge here on those obvious matters. One can be fooled of course; but it would be rash indeed to suggest that the thousands of UFO reports now on record are simply a testimony to confabulation, as will be better argued by some [selected cases]." Jones, who argues against the probability of any substantial number of flying saucers, says: "There have been so many flying saucers seen by now, if we were to believe the accounts, that surely one of them must have broken down or left some trace of its visits. It is true that one can explain the absence of relics by supposing . . . fantastic reliability . . ."

It would seem to me that if one begins by studying both witness reliability and selected cases, and if one thereby realizes that it is quite conceivable and probable for the great bulk of reports to be simple mistakes and fabrications, then arguments invoking the enormous number of reports become irrelevant. We are concerned by only a small "residual" of puzzling reports.

This raises another approach to the UFO "residual" reports. We could attempt to answer the question: what is the maximum frequency of spaceships that could actually have penetrated our airspace and still leave us with such meager evidence as we have for their existence? Obviously if a 30-ft. metal disk hovered over the Capitol for some hours, we would have a multitude of photos, video tapes, and other hard evidence from different observers in different positions.

Some measure of public reaction to spectacular and unfamiliar celestial phenomena can be gained from study of fireball reports. Six

spectacular fireballs were studied to this end using analyses by C. P. Olivier of the American Meteor Society (1962, 1963, 1967) and reports in *Sky and Telescope*. Among these, the longest duration was only 31 sec. for the 25 April 1966 object; yet even for an object of such short duration, a number of photographs were made. In other cases, dust trains of duration up to 17 min. were photographed and widely reported. The Zond IV observations are also applicable. These data permit estimates of the frequency of both visual and photographic reports.

The fireballs were brighter than the full moon in most cases. Often they appeared not as point sources, but as a disk about half the size of the moon. Some of them were bright enough to attract the attention of persons indoors; some of them were accompanied by thunder-like explosions. All attracted national publicity. In short, they are remarkable enough to have attracted attention and photographs, and are thus considered comparable to hypothetical, well-observed "flying saucers" in public response.

The analysis must take into account the number of inhabitants in the area of visibility as well as the duration of visibility. We may call the product of the number of inhabitants times the duration, the "exposure" of the phenomenon. We can ask how the total number of actual witnesses is related to the exposure.

For short-period durations (a few minutes) it is reasonable to expect that the number of witnesses (a fraction of the number of inhabitants) would be proportional to the exposure. This can also be assumed about the number of detailed reports recovered by investigators who solicit them, and about the number of photographs. In the fireball and Zond IV cases there are data giving number of witnesses, number of recovered reports, or number of photographs. Thus, if N is the total number of inhabitants, and t is the duration of the event (sec.), we have a first-order theory of the form

$$\text{no. witnesses} = N_w = C_w N t,$$

$$\text{no. recovered reports} = N_r = C_r Nt,$$

$$\text{no. recovered photographs} = N_p = C_p Nt.$$

It is possible to identify the proportionality constant, C from the reports mentioned above. Derived values are listed in Table 4. The constant 1/C has dimensions man-sec/witness (or /report, /photographer). For example, the Air Force files on Zond IV yield 78 reports for a two-minute phenomenon visible from a region inhabited by an estimated 23,000,000 persons, giving 3.5×10^7 man-sec to generate one report.

It is clear that the number of photographs generated will depend on the duration of the phenomenon in a more complex way than indicated in our simple equation, since with durations longer than some limit, more witnesses will have time to obtain a camera. In this approximate and first-order treatment, this complication is neglected.

Application of Table 4 can be illustrated by the fireball reports. The original data suggest about 500 reports in five years for these very bright objects. We assume that the average fireball is visible roughly 10 sec. These figures allow us to solve the equation (cited above) for the number of inhabitants through whose skies pass fireballs in five years. If it takes 6×10^6 man-sec. to generate one report (Table 4), then the fireballs must have been exposed to about 300,000,000 people. This figure is expected to be accurate to something better than an order of magnitude. That is, every citizen of the United States evidently has such a fireball in his sky about once every few years (whether or not he is outside and sees it). This is in good accord with known data - Vedder's (1966) estimate of the flux of meteors of magnitude -15 is one every three to four years over an area of the size of the United States.

The question before us is how many of the UFO reports could correspond to real objects in view of the available data. Is a "residual" of even 2% of the cases reasonable? We have three relevant statistics: (1) National opinion surveys indicate that roughly 5×10^6 persons of the total U. S. population believe they have seen UFOs in 20-year interval since they were first reported. If 2% of these represent

Table 4

Response to Unusual Aerial Objects*

Fireball Date	Location	$1/C_W$	$1/C_r$	$1/C_p$
17 November 1955	France		6.0×10^6	
16 January 1961	California	5.0×10^4		
23 April 1962	New Jersey		1.5×10^6	6.0×10^9
25 March 1963	Maryland		9.1×10^5	
9 December 1965	Michigan		5.3×10^6	$\leq 1.2 \times 10^{10}$
25 April 1966	New York	3.1×10^3	5.4×10^6	$\leq 4.0 \times 10^8$
3 March 1968	(Zond IV)		3.5×10^7	
Adopted value		10^4	6×10^6	5×10^9

*These figures are understood to apply only to short-duration sightings, since, obviously, by extending the duration one cannot obtain more witnesses than the number of inhabitants.

really strange unknowns, we should have 1×10^5 witnesses. (2) There have been roughly 15,000 recovered cases, representing perhaps 45,000 individuals' reports. A 2% residual would give 900 reports of unknowns. (3) The project study suggests that the "residual" photographs of unidentifieds number of the order of 20.

Combining these three statistics with the three constants from Table 4 we derive three independent estimates of the total number of citizens exposed to the "high-strangeness residual UFOs" in the last 20 years; viz., 2×10^7; 1×10^8; and 2×10^9. It can be seen that the accuracy is no better than an order of magnitude. However, taking 200,000,000 persons as a representative value, the implications are clear. The results suggest that merely to generate the 2% residual, every person in the country has had an UFO visible above his horizon once in the last 20 years.

Of course, since most man-hours in this country are spent indoors, or asleep, or paying no attention to the sky, it is not surprising that very few people have reported seeing such craft. But taking into account the array of automatic surveillance equipment operating in this country, it *does* border on the incredible that the "hard" evidence should be so scanty. The statistic is similar to the five-year statistic for bright fireballs, and although the "evidence gathered over an arbitrary five-year time span for the existence of bright fireballs" is similar to that gathered over 20 years for "flying saucers" the "fireball evidence" is perhaps more convincing : it includes detection by automatic survey cameras, large numbers of witnesses per incident, and more reliable witnesses. To accept as many as 2% residual cases as examples of extraordinary aircraft, then, is to accept that an UFO could fly around the country in such a way as to be *potentially* visible to, or in the sky of, every citizen for 40 sec. without being positively recorded or conclusively reported.

9. Conclusions

As we have already stated, some students of the UFO problem have used the argument, either directly or by implication, that where there

is so much smoke there must be some fire, i.e. that *some* of the UFO reports must involve truly extraordinary phenomena such as alien spaceships or unknown meteorological effects. This chapter is addressed to the question: is it conceivable and defensible that all of the UFO reports could result from mistakes, illusions, unusual conditions, and fabrications?

The answer appears clearly affirmative, although we claim no proof that all reports can be so explained. We have looked at a three-stage process: a *perception* is received of some unusual apparition; a *conception* is created by interpreting the percept and combining it with prior concepts; a *report* is eventually made to an investigator or on some public document. Each step introduces possibilities for error.

The number of phenomena and combinations of phenomena that can produce unusual percepts is so enormous that no investigation can begin with an *a priori* list of explanations and expect to match one to each case. The variety is effectively infinite and it must be realized that in effect the investigator is asking for a report each time an unusual percept is generated. Obviously, this will be frequent.

Our data demonstrates beyond question not only that weird and erroneous concepts are widely formed, but also that these erroneous concepts are often precisely those that show up in the UFO phenomenon. Perhaps as a result of their popularization in the UFO literature, the phenomenon feeds on itself to a certain extent.

Finally, the reporting processes are demonstrably such that very low signal-to-noise ratio is generated. That is, certain social forces conflict with clear, concise, and thorough presentation of UFO reports. Sarcasm is employed at the expense of logic. A whole body of literature exists by virtue of the sensational aspects of the problem.

In conclusion, it appears that the number of truly extraordinary events, i.e. sightings of alien spaceships or totally unknown physical-meteorological phenomena, can be limited to the range 0-2% of all the available reports, with 0 not being excluded as a defensible result.

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Chapter 3

Psychological Aspects of UFO Reports

Mark W. Rhine

Scientists investigating the phenomena of unidentified flying objects have been faced with an unusual dilemma: in the absence of any "hard data" to evaluate, such as a fragment from an UFO or an actual visitor from outer space, the scientist is confronted with the question of abandoning the entire investigation or of relying on eye-witness reports, a notoriously unreliable source of information. The scientist is most comfortable with data which can be replicated and validated by repeated experiment and which his colleagues can confirm.

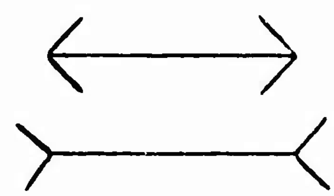
One way out of such a dilemma is, of course, to deal only with "hard data" and to reject eye-witness reports, with the rationalization that such reports are liable to distortion, cannot be "proved," or are apt to come from "crackpots." Such an attitude is as harmful to the pursuit of truth as is that which is uncritically willing to accept *any* eye-witness report. An open-minded investigator, honestly endeavoring to understand UFO phenomena, cannot dismiss eye-witness reports, which to date represent the only information he has. Neither can he accept such reports without scrutiny, for there are many possibilities for error and distortion. An initial attitude of "benevolent skepticism," as suggested by Walker (1968) in his excellent article on establishing observer creditability, seems appropriate to the evaluation of eye-witness observations.

Perception is an extraordinarily complex process by which people select, organize, and interpret sensory stimulation into a meaningful picture of the world (Berelson, 1964). Perception is more than just raw sensory data; it compromises the selection and interpretation of this data, and it is just in this evaluation of sensations that distortions are likely to occur which may render one person's perception

of an event quite different than his neighbor's. There are three broad sources of error in reporting which are of significance to UFO research: 1) real stimuli which are misidentified (see Section VI, Chapter 1 and 2); 2) unreal stimuli perceived as real; and 3) deliberate falsification.

1. Errors resulting from misidentification of real stimuli

Optical illusions and the fact that the mind is apt to "play tricks" are well known. The moon on the horizon appears larger than when it is higher in the sky. A stick in the water seems to be bent. Guilford (1929) showed that a small stationary source of light in a dark room will appear to move about (the autokinetic effect). "Floaters" in the lens of the eye are perceived as "spots" in the air. The following lines look to be of different lengths:



Measuring shows them to be exactly the same length.

These are perceptual distortions which are experienced by everyone. Other distortions may be peculiar to the individual because of his own psychological needs. It is common knowledge that "beauty is in the eye of the beholder." Poor children are more apt to overestimate the size of coins than are rich children (Bruner, 1947). Bruner showed that coins marked with a dollar sign were rated larger in size than equal coins marked with a swastika (Bruner, 1948). The psychological literature is full of reports of similar distortions of size, distance, and time and their relationship to individual emotional characteristics (Erikson, 1968; Forgus, 1966; Vernon, 1962). The concept of *perceptual defense* is used by psychologists to characterize the unconscious tendency of people to omit perceiving what they do not want to perceive (Erikson, 1968). Volunteers were more apt to recognize emotionally neutral words than emotionally laden words when they were briefly flashed on a screen (McGinnies, 1958).

All the above errors in perception occur in "normal" people in everyday situations. Some types of perceptual distortions are known to occur to normal people under extraordinary circumstances. Pilots, under the influence of rapid acceleration, diving, etc. may incur perceptual problems because of physiological changes which must be taken into account in evaluation of their sightings (Clark, 1957). In some delirious or toxic states (for example, resulting from pneumonia, drug ingestion, alcohol withdrawal), the patient will misidentify a stimulus. The example of a patient calling the doctor or nurse by the name of some friend or relative is quite common. Emotionally disturbed persons are more apt to misperceive than are more balanced individuals, but it should be emphasized that numerous distortions can afflict even the most "normal" individual and unwittingly bias his reports.

2. Errors resulting from perception of unreal stimuli as real

Such errors may be the result of psychopathology, as with the hallucinations of the psychotic. Unable to distinguish his inner productions from outer reality, he reports them as real. Anyone who has awakened abruptly from a dream not knowing where he is or whether or not he has been dreaming will recognize this feeling, which in the psychotic persists in the waking state, as if the psychotic were living in a waking dream. Such states may occur in healthy people under conditions of sensory deprivation: lone sailors have reported imaginary helmsmen who accompany them, poliomyelitis victims living in iron lungs have experienced hallucinations and delusions, often resembling traveling in vehicles resembling the respirator. Pilots may show detachment and confusion, (Clark, 1957) and long-distance truck drivers may develop inattention, disorientation, and hallucinations (McFarland, 1957). Radar operators show serious lapses of attention (Mackworth, 1950). Such possibilities must be considered in evaluating the reports of isolated people. Isolation experiments have shown the development of hallucinations in normal subjects. For an extensive review of this subject, see Ruff (1966). Such errors may also occur in children, in suggestible people, in persons of low intelligence, and in those subject to visions.

3. Deliberate falsification

People with serious character pathology may lie for many reasons: fame, notoriety, attention, money. They constitute a problem not only to UFO research but to the courts. An example of this type of person is the man who confesses to a crime which he did not commit.

4. The crowd effect

The above examples suggest some of the many sources of distortion in the perceptions of individuals. Put two or more individuals together, and the possibilities for distortion multiply. "Mass hysteria" is a familiar concept. Charles Mackay (1967) wrote a lengthy volume in 1841 entitled *Extraordinary Popular Delusions and the Madness of Crowds* in which he recounted many of the popular follies through the ages. Two incidents are of particular interest to UFO investigators because they show clearly the role of crowd psychology in times of imminent disaster: one is the great London panic of 1524 in which thousands left the city to avoid a great flood which a fortune-teller predicted and which, of course, never occurred; the other concerns an epidemic plague which afflicted Milan in 1630; the populace attributed the disaster to the Devil (the germ theory was still several centuries off), and one individual, brooding over the calamity until "he became firmly convinced that the wild flights of his own fancy were realities," related being swept through the streets in an air-borne chariot, accompanied by the Devil. Mackay notes in his foreword that "the present [volume] may be considered more a miscellany of delusions than a history--a chapter only in the great and awful book of human folly which yet remains to be written, and which Porson once jestingly said he would write in 500 volumes." One wonders if future historians may laugh as readily at our concerns about UFOs as we can about the London panic or the attempts to explain the plague of Milan.

Sharif (1935) demonstrated in a classic experiment the influence people have on one another's perceptions. He had a group of people observe a stationary light (such as Guilford used) in a darkened room. Although stationary, the light appeared to move, and in a different direction to each observer. The members of the group were able to eventually reconcile the initially divergent perceptions, and to agree

in what direction the light was "moving." Such ability to check out one's impressions with others and to get feedback is a healthy mechanism and accounts for one of the ways in which we confirm our perceptions. The unavailability of this mechanism may account for some of the misperception that occurs under conditions of sensory deprivation.

Although "feedback" from others is usually a healthy mechanism leading to a correction of misperceptions, under certain conditions it may lead to an exaggeration of faulty perceptions and to "mass hysteria." One of the best known examples in recent times was the "invasion from Mars" in 1938, when Orson Welles' radio broadcast of a science-fiction drama had thousands of listeners from coast-to-coast in a state of panic because they believed the Martians were really invading the earth and that the end of the world was at hand. Cantril's study (1966) of this incident, subtitled *A Study in the Psychology of Panic*, makes fascinating reading. He feels the anxieties of the times, the economic depression, and the imminent threat of war set the stage for the panic. He examines the psychological factors which made some people believe the broadcast to be true, whereas others regarded it as fiction or were able to ascertain what was happening (by checking other stations, phoning the police or newspapers, etc.). The believers seemed to have a "set," a preconceived notion that God was going to end the world, that an invasion was imminent, or had some fanciful notions about the possibilites of science. When they heard the broadcast, they immediately accepted it as proving what they had already believed, and tended to disregard any evidence which might disprove their immediate conclusions. Others showed poor judgment in checking out the show, using unreliable sources of confirmation and accepting their statement that the broadcast was real. Others, with no standard of judgment of their own, accepted without question what the radio said. Cantril concludes (p. 138) that this susceptible group is characterized by:

> a certain feeling of personal inadequacy. The individual is unable to rely on his own resources to see him through . . . [he] believes his life and fate are

> very largely dependent on some focus beyond his control, or on the whim of some supernatural being. All this adds up to an intense feeling of emotional insecurity, one which is likely to be augmented as the situation surrounding the individual appears more and more threatening . . . [he] will be highly susceptible to suggestion when he is face-to-face with a situation that taxes his own meager self-reliance . . . whatever critical ability a person may normally have, it is ineffective if in any given situation his emotional securities are so great that they overwhelm his good judgment. Such situations are likely to be those where the individual himself or something dear to him are threatened.

Another relevant study in social psychology is *The June Bug: A Study of Hysterical Contagion* (Kerckhoff, 1968). This is an account of a mysterious illness, manifested by nausea and a generalized rash, which afflicted some of the workers in a southern textile mill and was popularly attributed to the bite of an insect. The insect turned out to be non-existent and the symptoms were considered to be "hysterical." Only workers from one division of the factory were afflicted; the authors attributed the epidemic to the frustration and strain of a work situation (peculiar to the division in which the afflicted employees worked) from which there was no socially legitimate way to escape.

The June Bug contains an extensive review of the literature of "hysterical contagion," which is defined as "the dissemination of symptoms among a population in a situation where no manifest basis for the symptoms may be established," and where "a set of experiences or behaviors which are heavily laden with the emotion of fear of a mysterious force are disseminated through a collectivity . . . [it is] inexplicable in terms of the usual standards of mechanical, chemical, or physiological causality." Smelser (1963) is quoted as defining a hysterical belief as one "empowering an ambiguous element in the environment with a generalized power to destroy."

The possibility of hysterical contagion must be kept in mind in the evaluation of some UFO sighting reports.

The psychiatric literature on UFOs should be mentioned briefly. In comparison with the vast popular literature, the psychiatric literature is surprisingly scant. The only extensive work of which this author is aware is a volume by the late Swiss psychoanalyst, C. G. Jung, entitled *Flying Saucers: A Modern Myth of Things Seen in the Skies* (1959). Noting the tendency to welcome news about "saucers" and to suppress skepticism Jung raises the interesting question "why should it be more desirable for saucers to exist than not?" He feels that their appearance since World War II is a reflection of the anxieties of a nuclear age, in which man possesses the capability of actually destroying the world. Saucers may represent man's anxiety that the end of the world is here, or may represent a superhuman source of salvation. Historically, man's anxiety and his quest for salvation have been projected in many legendary and religious forms, but in an era of rapid technological and scientific advance including space flight, it is not suprising to find "scientific" rather than religious imagery. Other authors have mentioned the anxieties of the nuclear age and the personal search for magic as contributing to some of the belief in UFOs (Meerloo, 1968).

5. Medical and psychological techniques

It is clear that there are many factors which may influence perceptions and reporting. The investigator must be aware of possible sources of subjective interpretation by witnesses which may complicate the problem of arriving at the truth about UFOs. How can the investigator minimize such subjective error? Walker's recommendations on establishing observer creditability are excellent. He examines in detail the anatomic, physiologic, and psychological factors influencing perception and their many aberrations, and recommends a detailed medical, ophthalmological, and a neurological examination, and in those individuals who show no organic impairment, a full psychiatric interview. The testimony of any observer who shows no significant medical or psychological conditions which might distort perception or interpretation must gain in

creditability. I would suggest that, in addition to Walker's detailed recommendations, the use of psychological testing (expecially projective tests such as the Rorschach and the Thematic Apperception Test) be used when recommended by the psychiatrist. A psychiatric interview, if made a routine part of the evaluation of observers, should carry no social stigma.

Two adjuncts to the psychiatric evaluation must be mentioned. The polygraph (lie detector) may occasionally be used where deliberate falsification is suspected. The test is useful, but not fool-proof. The use of hypnosis has been reported in at least one of the popular accounts of UFO sightings to establish the "truth" of the observations (Fuller, 1966). Statements made under hypnosis are gradually acquiring greater legal acceptability (Katz, 1967; Bryan, 1962), but the fact remains that neither the evidence adduced from the use of a polygraph nor that obtained by hypnotic techniques can be relied upon as probative. Hypnosis has nothing to contribute to the routine evaluation of the creditability of tha eye-witness. While it may occasionally be useful as a source of information, is cannot be used as a way of *proving* that the witness is telling the truth. Sometimes hypnosis can aid in bringing to conscious awareness, material that has been repressed. But persons who cannot distinguish their fantasies from reality will, under hypnosis only reveal more of the same fantasies. Their productions under hypnotic trance will demonstrate only that their reports are "real" to them, even though they may not in fact have any basis in objective reality. Wolberg (1966) states:

> It is essential not to take at face value memories and experiences recounted in the trance. Generally, the productions elaborated by a person during hypnosis are a fusion of real experiences and fantasies. However, the fantasies in themselves are significant, perhaps, even more than the actual happenings with which they are blended. Asking a patient to recall only real events or to verify the material as true or false, reduces but does not remove the element of fantasy.

In addition to the evaluation of individual observers, it would seem wise in future investigations to make use of sociologists and psychologists in those cases where more than one person has made a sighting, to rule out the possibility of hysterical contagion, as well as to contribute to our knowledge of this condition. There should be opportunity to investigate both people who sight UFOs and those who do not.

This chapter raises more questions than it answers. There are many interesting psychological questions: Why have some fervid "believers" in UFOs never seen one? Why do some persons who see an UFO regard it as simply an unidentified aerial phenomenon, while others are sure it is a "space vehicle ?" Why do some refuse to accept evidence that what they saw was really an airplane, weather balloon, etc., while others readily accept such explanations? The answers to such questions must await future research. It was not the purpose of the project to explore the psychology of UFO sighters, but rather to explore the nature of the UFOs themselves.

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Chapter 4

Optical Mirage

William Viezee

1. Introduction

An optical mirage is a phenomenon associated with the refraction of light in the gaseous (cloud-free) atmosphere. During mirage a visible image of some distant object is made to appear displaced from the true position of the object. The image is produced when the light energy emanating from the distant source travels along a curvilinear instead of a rectilinear path, the curvilinear path, in turn, arises from abnormal spatial variations in density that are invariably associated with abnormal temperature gradients.

The visible image of the mirage can represent shape and color of the "mirrored" object either exactly or distorted. Distortions most commonly consist of an exaggerated elongation, an exaggerated broadening, or a complete or partial inversion of the object shape. Frequently, mirages involve multiple images of a single source. Under special conditions, refractive separation of the color components of white light can enhance the observation of a mirage. Atmospheric scintillation can introduce rapid variations in position, brightness, and color variations of the image.

When both the observer and the source are stationary, a mirage can be observed for several hours. However, when either one or both are in motion, a mirage image may appear for a duration of only seconds or minutes.

Although men have observed mirages since the beginning of recorded history, extensive studies of the phenomenon did not begin till the last part of the 18th century. Since that time, however, a large volume of literature has become available from which emerges a clear picture of the nature of the mirage.

The comprehensive body of information presented here is based on a survey of the literature, and constitutes the state-of-the-art knowledge on optical mirages. The report provides a ready source of up-to-date information that can be applied to problems involving optical mirages.

No claim is made that *all* existing pertinent writings have been collected and read. The contents of many publications, especially of those dating back to the last part of the 18th Century and the beginning of the 19th Century are evaluated from available summaries and historical reviews. Also, when a particular aspect of the mirage phenomenon is considered, the collection of pertinent literature is discontinued at the point where the state-of-the-art knowledge appears clearly defined. The collected volume of literature covers the period 1796 to 1967.

In essence, the literature survey yields the following principal characteristics of the mirage: (1) Mirages are associated with anomalous temperature gradients in the atmosphere. (2) Mirage images are observed almost exclusively at small angles above or below the horizontal plane of view; mirages, therefore, require terrain and meteorological conditions that provide extended horizontal visibility. (3) A mirage can involve the simultaneous occurrence of more than one image of the "mirrored" object; the images can have grossly distorted forms and unusual coloring. (4) Extreme brightening and apparent rapid movement of th[illegible]age image in and near the horizontal plane can result from the effects of focussing and interference of wavefronts in selected areas of the refracting layer.

Only minor shortcomings appear to be evident in present knowledge of mirage phenomena. Ultimately, a unified theory is desirable that can deal with both the macroscopic and microscopic aspects. Currently, the behavior of light refraction on a large scale is represented by means of rays while the finer details are treated with the wave theory. More observations are needed that deal with the microscopic optical effects of the mirage. The finer details that arise mostly from focussing and interference are not commonly observed. They require close examination of areas that are highly selective in time and place.

2. Cross Section of Surveyed Literature

The contents of this report are based on a survey of literature on atmospheric refraction in general and on optical mirages in particular. The survey began with the review of such basic sources of information on atmospheric optics as *Meteorologische Optik*, by Pernter and Exner, *Physics of the Air*, by Humphreys, *The Nature of Light and Colour in the Open Air*,

by Minnaert, and *The Compendium of Meteorology*. These sources present historical summaries, and their contents are to a large extent based on literature surveys. Key references mentioned in these sources were examined and a large volume of literature was subsequently collected by following successive reference leads. Pertinent information on atmospheric scintillation was obtained from several sources, in particular from *Optical Scintillation; A Survey of the Literature*, by J. R. Meyer-Arendt. A cross section of the collected literature is listed below. Because of the wide range of aspects covered, the literature is listed in the following categories: (1) papers on optical mirage the contents of which are mostly descriptive, (2) papers that propose theoretical models of atmospheric refraction or optical mirage, (3) papers that compare theory and observation, (4) papers that are concerned with the application of terrestrial light refraction to meteorology, surveying, and hydrography, (5) papers that present average values of terrestrial refraction based on climatology, and (6) papers on atmospheric scintillation. Within each category, publications are arranged chronologically.

In Category 1, descriptive accounts of mirages go back in time to 1796, when Joseph Huddart observed superior mirages near Macao. (Earlier accounts can be found in *Meteorologische Optik.)* Numerous recent observations of abnormal atmospheric refraction can be found in *The Marine Observer*. The two "classical" observations most frequently quoted as having "triggered" a long series of investigations on optical mirage are the observations of Vince and Scoresby. Vince (1798) from a position on the sea shore observed multiple images of ships, some upright and some inverted, above the ocean horizon; Scoresby (1820) observed elevated images of ships and coastal lines while navigating near Greenland. Both observations were carefully documented and results were read before bodies of the Royal Society.

Proposed theories of the mirage (category 2) are basically of three types, that are best represented by the respective works of Tait (1883), Wegener (1918), and Sir C. V. Raman (1959). Tait (in his efforts to explain the observations by Vince and Scoresby) considers a vertically

finite refracting layer having a continuous change in refractive index, and formulates the ray paths for a plane-stratified atmosphere. Wegener (motivated by mirage observations made during his stay in Greenland) replaces Tait's finite refraction layer with a "reflecting" surface - *i.e.*, a surface of discontinuity in the refractive index - and formulates the ray paths for a spherically stratified atmosphere. Raman questions the use of geometric optics in the theory of the mirage and shows by means of physical optics that the upper boundary of the refracting layer resembles a caustic surface in the vicinity of which focussing and interference are the major mirage-producing effects. All three theories quite accurately describe various mirage observations.

Comparisons made between observation and theory (category 3) indicate that the two are compatible - *i.e.*, abnormal light-refraction phenomena are associated with anomalous atmospheric-temperature structure. Many investigations (category 4) are concerned with determining the effects of light refraction on optical measurements made in such fields as surveying and hydrography. Corrections for refraction based on average atmospheric conditions have been computed (category 5). Of specific interest to meteorologists are the attempts to develop inversion techniques for obtaining low-level temperature structure from light-refraction measurements (category 4). The temperature profiles that can be obtained do not have the desired resolution and accuracy. During the last decade, literature on atmospheric scintillation has become extensive due to its importance to astronomy, optical communication, and optical ranging. A selected number of recent papers are presented in category 6.

The publications categorized below represent a cross section of the various endeavors that have resulted from the Earth's atmosphere having light-refraction properties. The body of information is fundamental to the contents of this report. In addition to the listed literature, many other sources of information on atmospheric optics were consulted in its production. They are referenced throughout the text, and are compiled in a bibliography at the end of the report.

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3. Basic Physical Concepts and Atmospheric Variables Involved in Light Refraction

A. General

In a vacuum or in a medium of constant density, the energy from a light-emitting source travels along a straight line. Consequently, a distant observer sees the light source at its exact location. In a medium of variable density, such as the earth's atmosphere, the direction of energy propagation is deflected from a straight line; i.e., refracted. Refraction causes an observer to see a distant light source at an apparent position that differs from the true position by an angular distance the magnitude of which depends on the degree of refraction, i.e. on the degree of density variation between the observer and the light source. Changes in the direction of energy propagation arise principally from changes in the speed of energy propagation. The latter is directly related to density.

A clear picture of what causes refraction is obtained by means of Huygen's principle which states that each point on a wavefront may be regarded as the source or center of "secondary waves" or "secondary disturbances," At a given instant, the wavefront is the envelope of the centers of the secondary disturbances. In the case of a travelling wavefront the center of each secondary disturbance propagates in a direction perpendicular to the wavefront. When the velocity of propagation varies along the wavefront the disturbances travel different distances so that the orientation of their enveloping surface changes in time, i.e., the direction of propagation of the wavefront changes.

Practically all large-scale effects of atmospheric refraction can be explained by the use of geometrical optics, which is the method of tracing light rays -- i.e., of following directions of energy flow. The laws that form the basis of geometrical optics are the law of reflection (formulated by Fresnel) and the law of refraction (formulated by Snell). When a ray of light strikes a sharp boundary that separates two transparent media in which the velocity of light is appreciably different,

such as a glass plate or a water surface, the light ray is in general divided into a reflected and a refracted part. Such surfaces of discontinuity in light velocity do not exist in the cloud-free atmosphere. Instead changes in the speed of energy propagation are continuous and are large only over layers that are thick compared to the optical wavelengths. It has been shown (J. Wallot, 1919) that, in this case, the reflected part of the incident radiation is negligible so that all the energy is contained in the refracted part. Since in the lower atmosphere, where mirages are most common, absorption of optical radiation in a layer of the thickness of one wavelength is negligible, Snell's law of refraction forms the basis of practically all investigations of large-scale optical phenomena that are due to atmospheric refraction (Paul S. Epstein, 1930).

B. Optical Refractive-Index of the Atmosphere

The optical refractive index (n) is defined as the ratio of the velocity (v) at which monochromatic (single wavelength) light is propagated in a homogeneous, isotropic, non-conductive medium, to the velocity (c) of light in free space, i.e., $n = c/v$. In free space, i.e., outside the earth's atmosphere, $n = 1$. Thus, in the case of a monochromatic light signal travelling through a given medium, $c/v > 1$. In case the light signal is not monochromatic and the velocities (v) of the component waves vary with wavelength (λ), the energy of the signal is propagated with a group velocity u where $u = v - \lambda(dv/d\lambda)$. The group refractive index is given by $c/u = n - \lambda(dn/d\lambda)$ (Jenkins and White, 1957). In the visible region of the electromagnetic spectrum the dispersion, $dn/d\lambda$ is very small (see Table 1) and a group index is nearly equal to the index at the mean wavelength.

For a gas, the refractive index is proportional to the density ρ of the gas. This can be expressed by the Gladstone-Dale relation:

$$\boxed{n - 1 = k\rho \equiv k\,\frac{P}{RT}} \tag{1}$$

Table 1

DEPENDENCE OF OPTICAL REFRACTIVE-INDEX
ON ATMOSPHERIC PRESSURE, TEMPERATURE AND WAVELENGTH

(a) Pressure Dependence

Conditions: 5455 A, 15°C	
P, mb	n
1,000	1.000274
950	1.000260
900	1.000246

(b) Temperature Dependence

Conditions: 5455 A, 1013.3 mb	
T, °C	n
0	1.000292
15	1.000277
30	1.000263

(c) Wavelength Dependence

Conditions: 1013.3 mb, 15°C	
λ, A	n
4,000	1.000282
5,000	1.000278
6,000	1.000276
7,000	1.000275
8,000	1.000275

where k is a wavelength-dependent constant, P and T are the pressure and temperature, and R is the gas constant. The refractive index of a mixture of gases, such as the earth's atmosphere, is generally assumed to obey the additive rule, that is, the total value of $n - 1$ is equal to the sum of the contributions from the constituent gases weighted by their partial pressures. When the atmosphere is considered as a mixture of dry air and water vapor,

$$(n - 1)P = (P - e)\ (n_d - 1) + e(n_v - 1)$$

or

$$n = n_d - \frac{e}{P}\,(n_d - n_v)$$

where P denotes the total pressure of the mixture, e the partial water vapor pressure and the subscripts d and v refer to dry air and water vapor, respectively. Using Eq. (1), the refractive index n of the moist air at any temperature T and pressure P can be written

$$n - 1 = \frac{PT_o}{TP_o}\left\{n_d - 1 - \frac{e}{P}(n_d - n_v)\right\}$$

where n_d and n_v are the refractive indices at P_o and T_o. For λ = 5455 A^o (about the center of the visible spectrum), at P_o = 1013.3 mb (760 mm Hg) and $T_o = 273^oK$, $n_d = 1.000292$ and $n_v = 1.000257$, so that

$$n - 1 = (78.7 \times 10^{-6})\frac{P}{T}\left(1 - 0.12\,\frac{e}{P}\right)$$

For P = 1013.3 mb, maximum values of e/P(air saturated with water vapor) for a range of tropospheric temperatures are as follows:

$T(^oK)$	273	283	288	293	298	303
e/P	0.006	0.012	0.017	0.023	0.031	0.042

It is evident that in problems related to terrestrial light refraction the effects of humidity on the atmospheric refractive index are negligible. It is of interest to compare the formula for the optical refractive-index with that for radio waves in the centimeter range. The latter can be written

$$(n - 1) = (77.6 \times 10^{-6})\ \frac{P}{T}\ \left(1 + \frac{4810}{T}\,\frac{e}{P}\right)$$

The formula for the optical refractive index can be written

$$n - 1 = k \frac{P}{R_d T}$$

where R_d = gas constant for dry air. By introducing k as a function of wavelength (Johnson, 1954), a final expression for the optical refractive-index in the atmosphere can be written as

$$n - 1 = A + \frac{B}{\sigma_{o_1}^2 - \sigma^2} + \frac{C}{\sigma_{o_2}^2 - \sigma^2} \qquad (2)$$

where the σ_o are resonance lines and σ is the wavenumber in inverse microns (i.e. $1/\lambda$). The latest equation is (Edlén, 1966):

$$(n_a - 1) \times 10^6 = (77.49_7 \pm 0.01_3) \frac{P_a}{T} Z_a^{-1} \left[0.30600_7 + \frac{88.2581}{130 - \sigma^2} + \frac{0.5868}{38.9 - \sigma^2}\right]$$

where n_a is the refractive index of dry air containing 0.03% CO_2, P_a is the partial pressure of dry air, and Z_a^{-1} is the inverse compressibility factor for dry air (Owens, 1967). Z_a^{-1} is very close to unity; for P_a = 1013.25 mb, T = 288.16°K (15°C), $Z_a^{-1} - 1 = 4.15 \times 10^{-4}$. The standard value of Z_a^{-1} is assumed, i.e., the constant is

$$77.49_7 \times 1.000415 \simeq 77.5_3.$$

Table 1 gives the range of n for various ranges of atmospheric pressure, temperature, and wavelength. The listed values are of sufficient accuracy for a discussion of optical mirage. For a more recent version of Eq. (2) and differences in n smaller than 10^{-6} reference is made to the detailed work by Owens (1967).

Table 1 shows that the optical refractive index of the atmosphere is a relatively small quantity and that its largest variations with temperature, pressure and wavelength are of the order of 10^{-5}. Such small changes in the refractive index correspond to relatively small changes in the direction of optical-energy propagation. Hence, an optical image that arises from atmospheric light refraction cannot be expected to have a large angular displacement from the light source.

C. Snell's Law of Refraction

Snell's law, formulated for the refraction at a boundary, may be stated as follows: the refracted ray lies in the plane of incidence, and the ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant. The constant is equal to the ratio of the indices of refraction of the two media separated by the boundary. Thus, Snell's law of refraction requires that:

$$\frac{\sin\phi}{\sin\phi'} = \frac{n'}{n}$$

where ϕ and ϕ' are the angles of incidence and refraction respectively in the first and second medium, while n and n' are the corresponding values of the refractive index (see Fig. 1).

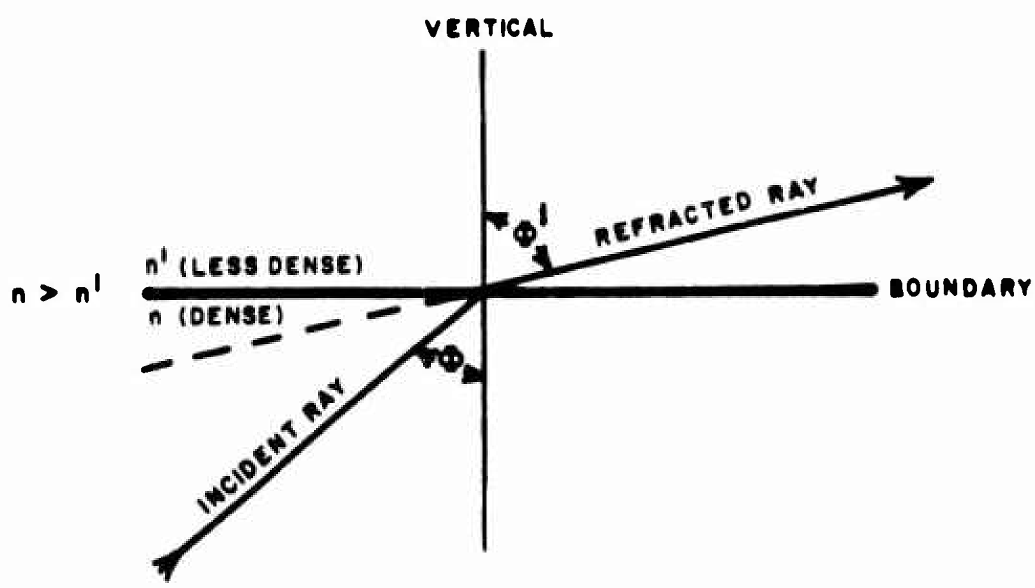


FIG. 1 SNELL'S LAW OF REFRACTION

The angle of refraction (ϕ') is always larger than the angle of incidence (ϕ) when $n > n'$, and the direction of energy propagation is from dense-to-rare. The critical angle of incidence (ϕ_c) beyond which no refracted light is possible can be found from Snell's law by substituting $\phi' = 90^o$. Thus,

$$\sin \phi_c = \frac{n'}{n}$$

For all angles of incidence $>\phi_c$ the incident energy is *totally reflected,* and the angle of reflection equals the angle of incidence (Goos and Haenchen, 1947).

Mirages arise under atmospheric conditions that involve "total reflection." Under such conditions the direction of energy propagation is from dense-to-rare, and the angle of incidence exceeds the critical angle such that the energy is not transmitted through the refracting layer but is "mirrored." The concept of total reflection is most rigorously applied by Wegener in his theoretical model of atmospheric refraction (Wegener, 1918).

Snell's law can be put into a form that enables the construction of a light ray in a horizontal layer wherein the refractive index changes continuously. Introducing a nondimensional rectangular ϕ, z coordinate system with the χ-axis in the horizontal, $\tan\phi = d\chi/dz$, where ϕ denotes the angle between the vertical axis and the direction of energy propagation in the plane of the coordinate system. Snell's law can now be applied by writing

$$\tan\phi = \frac{\sin\phi}{\cos\phi} = \frac{\sin\phi}{\sqrt{1-\sin^2\phi}} = \frac{d\chi}{dz}$$

and

$$\sin\phi = \frac{n_o \sin\phi_0}{n}$$

where n_o and ϕ_o are initial values. Substitution gives

$$\frac{d\chi}{dz} = \frac{n_0 \sin\phi_0/n}{\sqrt{1 - \dfrac{n_0^2 \sin^2\phi_o}{n^2}}} = \frac{n_0 \sin\phi_0}{\sqrt{n^2 - n_0^2 \sin^2\phi_0}} \qquad (3)$$

When the refractive index n is expressed as a continuous function of χ and z, the solution to the differential equation (3) gives a curve in the χ, z plane that represents the light ray emanating to the point (n_0, ϕ_0). For example, when n^2 decreases linearly with z according to $n^2 = n_0^2$ [illegible] z. Eq. (3) can be integrated in the form

$$\chi = \int \frac{n_0 \sin \phi_0}{\sqrt{n_0^2 \cos^2 \phi_0 - z}} \, dz$$

For an initial refractive index n_0 and an initial direction of energy flow θ_0, integration between 0 and z gives:

$$\chi = n_0^2 \sin 2\theta_0 - 2n_0 \sin \theta_0 \sqrt{n_0^2 \cos^2 \theta_0 - z}$$

This equation represents a parabola. Hence, for a medium in which n changes with z in the above prescribed fashion, the rays emanating from a given light source are a family of parabolas.

When the ordinate of the nondimensional coordinate system is to represent height, z must represent a quantity az', where z' has units of height and a is the scale factor.

By introducing more complicated refractive-index profiles into Eq. (3), the paths of the refracted rays from an extended light source can be obtained and mirage images can be constructed. Tait and other investigators have successfully used this method to explain various mirage observations.

Application of Eq. (3) is restricted to light refraction in a plane-stratified atmosphere and to refractive-index profiles that permit its integration.

D. Partial Reflections from Atmospheric Layers

The theory of ray tracing or geometrical optics does not indicate the existence of partial reflections, which occur wherever there is an abrupt change in the direction of propagation of a wavefront. An approximate solution to the wave equation may be obtained for the reflection coefficient applicable to a thin atmospheric layer (Wait, 1962):

$$R \cong \left| \frac{\sec^2 \phi}{2} \int_{Z_1}^{Z_2} \left[\frac{dn}{dz}\right] e^{-2ik_0 \cos\phi Z} \, dz \right|$$

where R is the power reflection coefficient, ϕ the angle of incidence, Z is height through a layer bounded by Z_1 and Z_2, and K_o is the vacuum wavenumber $K_o = 2\pi/\lambda$. The equation is generally valid only when the value of R is quite small, say $R < 10^{-4}$.

This result can be applied to atmospheric layers of known thickness and refractive index distribution; the most convenient model is that in which dn/dz = const. for $Z_1 \leq Z \leq Z_2$ and $dn/dz = 0$ everywhere else. Although some authors have argued that the reflection coefficient using this model depends critically upon the discontinuity in du/dz at the layer boundaries, it can be shown using continuous analytic models that the results will be the same for any functional dependence so long as the transition from $dn/dz = 0$ to dn/dz = const. occurs over a space that is not large compared to the effective wavelength. The effective wavelength is defined as $\lambda \sec\phi$. For the simple linear model, R is given by

$$R \cong \left[\frac{\Delta n}{2} \sec^2\phi \ \frac{\sin\alpha}{\alpha}\right]^2$$

where $\alpha = K_o \cos\phi h$, Δn is the total change in n through the layer, and h is the thickness of the layer, $h = Z_2 - Z_1$. For large values of h/λ, and hence large values of α, the term $\sin\alpha/\alpha$ may be approximated as $1/\alpha$ for maxima of $\sin\alpha$. Since h/λ is always large for optical wavelengths, e.g. $h/\lambda \cong 2 \times 10^4$ for a layer 1 cm thick, the power reflection coefficient may be approximated by

$$R \cong \left[\frac{\Delta n}{4\pi}\left(\frac{\lambda_o}{h}\right)\right]^2 \sec^6\phi$$

Atmospheric layers with $\Delta n \cong 3.0 \times 10^{-6}$ and h = 1 cm are known to exist in the surface boundary layer, e.g. producing inferior mirage. For visible light with a "center wavelength" of 5.6×10^{-5} cm (0.56μ), λ_o/h is thus 5.6×10^{-5}. R then becomes

$$R \cong 1.6 \times 10^{-20} \sec^6 \phi.$$

This is a very small reflection coefficient, and light from even the brightest sources reflected at normal incidence by such a layer would be invisible to the human eye. The situation may be different at grazing incidence or large ϕ; for a grazing angle of 1°, $\phi = 89^{\circ}$, $\sec^{6}\phi \cong 3.54 \times 10^{10}$, and

$$R \cong 5.6 \times 10^{-10}, \; \phi = 89^{\circ}$$

The critical grazing angle, θ_c, for a total reflection for the thin layer under discussion is given by $\theta_c \cong \sqrt{2\Delta n}$, which yields a value of 0.007746 rad or 26.6'. Substituting $\phi = 89^{\circ}$ 33.4' in the equation for R gives

$$R \cong 7.4 \times 10^{-8}, \; \phi = 89^{\circ}\ 33.4'$$

Since the human eye is capable of recording differences at least as great as 3.5×10^{-8} (Minnaert, 1954), partial reflections of strong light sources may occasionally be visible. The theoretical treatment discussed here shows that as the critical angle for a mirage is exceeded there should be a drop in reflected intensity on the order of 10^{-7} - 10^{-8}, so that instead of a smooth transition from totally to partially reflecting regimes, there should be a sharp decrease giving the impression of a complete disappearance of the reflection. This is in agreement with observation. The theory also indicates that faint images produced by partial reflection of very bright light sources, e.g. arc lights, may be seen at angles somewhat larger than the critical angle for a true mirage.

E. Spatial Variations in the Atmospheric Index-of-Refraction

As dictated by Snell's law, refraction of light in the earth's atmosphere arises from *spatial variations* in the optical refractive-index. Since $n = f(P,T,\lambda)$ according to Eq. (2), the spatial variations of $n(\lambda)$ can be expressed in terms of the spatial variations of atmospheric pressure and temperature. Routine measurements of the latter two quantities are made by a network of meteorological surface observations and upper-air soundings. When the optical wavelength dependence of n is neglected, Eq. (2) takes the form (for $\lambda \approx$ 5455 Å,

$$n - 1 = (78.7 \times 10^{-6}) \frac{P}{T}$$

and the gradient of n is given by

$$\nabla n = (78.7 \times 10^{-6})\left(\frac{1}{T}\,\nabla P - \frac{P}{T^2}\,\nabla T\right)$$

Optical mirages are most likely to form when atmospheric conditions of relative calm (no heavy cloudiness, no precipitation or strong winds) and extended horizontal visibility (<10 miles) are combined with large radiative heating or cooling of the earth's surface. Under these conditions the vertical gradients of pressure and temperature are much larger than the horizontal gradients, i.e., the atmosphere tends to be horizontally stratified.* Thus,

$$\nabla n = \frac{\partial n}{\partial z} = (78.7 \times 10^{-6})\left(\frac{1}{T}\,\frac{\partial P}{\partial z} - \frac{P}{T^2}\,\frac{\partial T}{\partial z}\right)$$

or

$$\frac{\partial n}{\partial z} = (78.7 \times 10^{-6})\,\frac{P}{T^2}\left(\frac{-g}{R_d} - \frac{\partial T}{\partial z}\right)$$

$$\boxed{\frac{\partial n}{\partial z} = (78.7 \times 10^{-6})\,\frac{P}{T^2}\,(-3.4^{\circ}\text{C}/100\text{ m.} - \frac{\partial T}{\partial z}} \qquad (4)$$

Thus, the spatial variation in the refractive index, i.e., light refraction, depends primarily on the vertical temperature gradient. When $\partial n/\partial z$ is negative and the direction of energy propagation is from dense to rare, the curvature of light rays in the earth's atmosphere is in the same sense as that of the earth's surface. Equation (4) shows that $\partial n/\partial z$ is negative for all vertical gradients of temperature except those for which the temperature decreases with height $\geq$ 3.4°C/100 m. No light refraction takes place when $\partial n/\partial z = 0$; in this case $\partial T/\partial z = -3.4^{\circ}$ C/100 m. which is the autoconvective lapse rate, i.e., the vertical temperature-gradient in an atmosphere of constant density. Table 2 gives the curvature of a light ray in seconds of arc per kilometer for various values of $\partial T/\partial z$ near the surface of the earth (standard P and T). When ray curvature is positive, it is in the same sense as an earth's curvature.

*When horizontal gradients in the refractive index are present, the complex mirage images that occur are often referred to as Fata Morgana. It is believed, however, that the vertical gradient is the determining factor in the formation of most images.

Table 2

CURVATURE OF LIGHT RAYS FOR VARIOUS VALUES OF VERTICAL TEMPERATURE-GRADIENT AT STANDARD CONDITIONS OF PRESSURE (1013.3 mb) AND TEMPERATURE (273°K)

$\frac{\partial T}{\partial z}$ (°C/100m)	CURVATURE OF LIGHT RAYS ("/km)
-3.4	0
-1.0	5.3
-0.5	6.4
0	7.5
+6.9	22.7
+11.6	33.0

From Table 2 it is evident that two types of vertical temperature variation contribute most to the formation of mirages; these are temperature inversions $[(\partial T/\partial z)>0]$ and temperature lapse rates exceeding 3.4°C/100m (the autoconvective lapse rate). Superautoconvective lapse rates cause light rays to have negative curvature (concave upward), and are responsible for the formation of inferior mirages (e.g., road mirage). The curvature of the earth's surface is 33"/km, and thus whenever there is a sufficiently strong temperature inversion, light rays propagating at low angles will follow the curvature of the earth beyond the normal horizon. This is the mechanism responsible for the formation of prominent superior mirages.

F. Meteorological Conditions Conducive to the Formation of Mirages

The strength and frequency of vertical temperature gradients in the earth's atmosphere are constantly monitored by meteorologists. The largest temperature changes with height are found in the first 1,000 m above the earth's surface. In this layer, maximum temperature gradients usually arise from the combined effects of differential air motion and radiative heating or cooling.

The temperature increase through a low-level inversion layer can vary from a few degrees to as much as 30°C during nighttime cooling of the ground layer. During daytime heating, the temperature can drop by as much as 20°C in the first couple of meters above the ground

(*Handbook of Geophysics and Space Environments*, 1965). Large temperature lapses are generally restricted to narrow layers above those ground surfaces that rapidly absorb but poorly conduct solar radiation. Temperature inversions that are due to radiative cooling are not as selective as to the nature of the lower boundary and are therefore more common and more extensive than large lapses. Temperature inversions can extend over horizontal distances of more than 100 km. Large temperature lapses, however, do not usually extend uninterrupted over distances more than a couple of kilometers.

At any given location, the frequency of occurrence of large temperature lapses is directly related to the frequency of occurrence of warm sunny days. Fig. 2 shows the *average* distribution of normal summer sunshine across the United States (Visher, 1954). More than seventy percent of the possible total is recorded in a large area extending from the Mississippi to the West Coast. Consequently, low-level mirages associated with large temperature lapses may be rather normal phenomena in this area. Distribution for summer and winter of the frequency of occurrence of temperature inversions ≤ 150 m above ground level are shown for the United States in Fig. 3 (Hosler, 1961). The data are based on a two-year sampling period. Figure 4 shows the distribution across the United States of the percentage of time that the visibility exceeds 10 km (Eldridge, 1966). When Figs. 3 and 4 are combined it is seen that large areas between roughly the Mississippi and the West Coast have a high frequency of extended horizontal visibility and a relatively high frequency of low-level temperature inversions. These meteorological conditions are favorable for the formation of mirages. On the basis of the climatic data shown in Figs. 2, 3, and 4 it can be concluded that at some places a low-level mirage may be a rather normal phenomenon while in other places it may be highly abnormal. An example of the sometimes daily recurrence of superior mirage over the northern part of the Gulf of California is discussed by Ronald Ives (1968). Temperature inversions in the cloud-free atmosphere are often recorded at heights up to 6,000 m above the ground. These elevated inversions usually arise from descending air motions, although radiative processes can be involved when very thin cirrus clouds or haze layers are present. Narrow

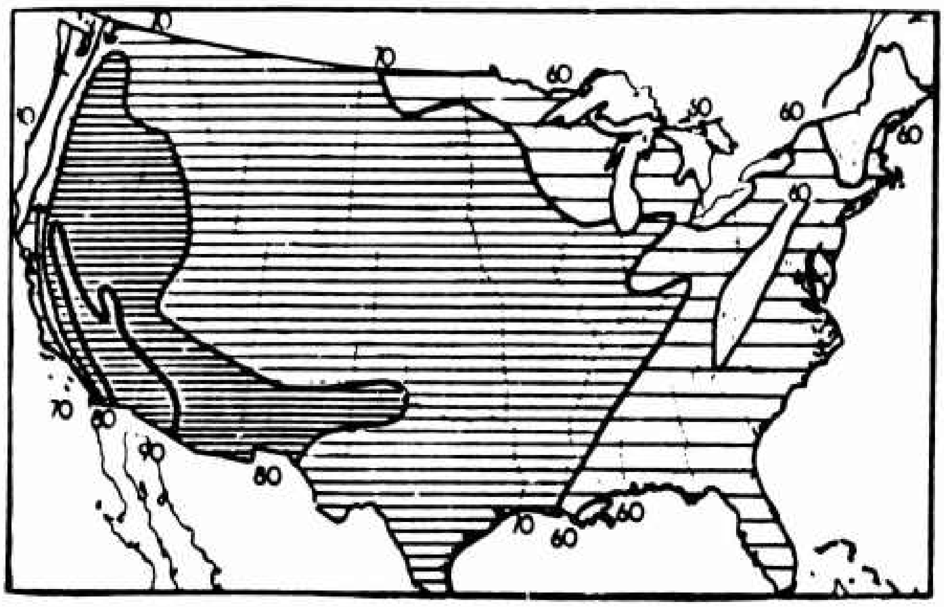


FIG. 2 DISTRIBUTION OF NORMAL SUMMER SUNSHINE (Percentage of Possible Total)

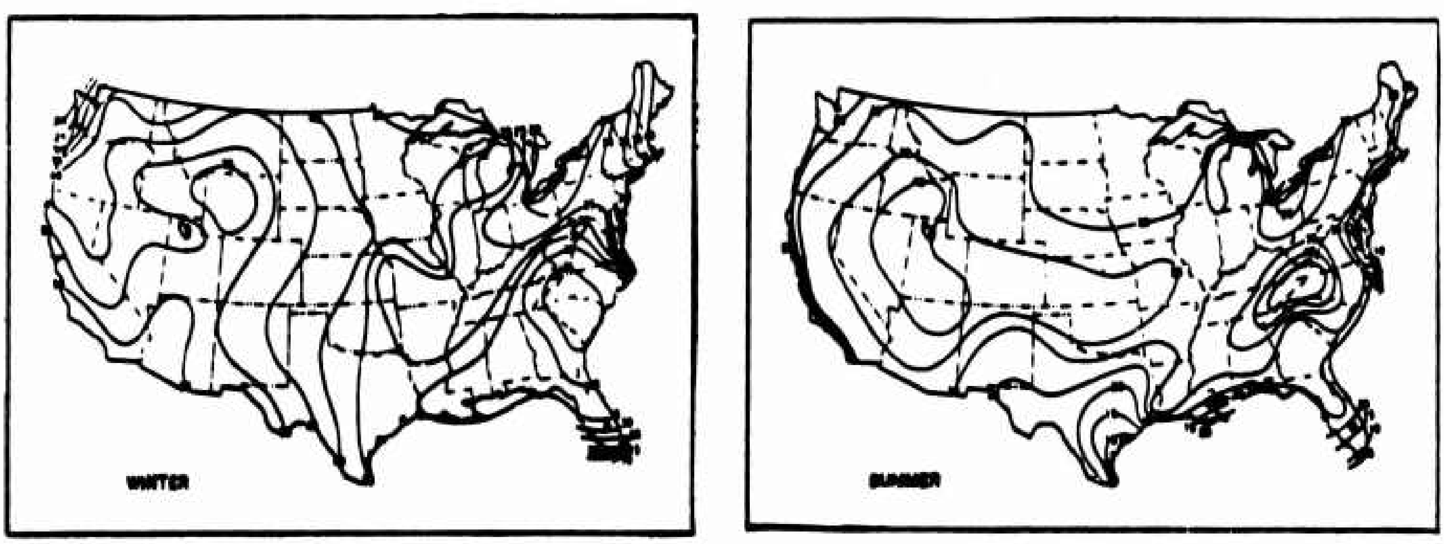


FIG. 3 DISTRIBUTION OF INVERSION FREQUENCY (Percent of Total Hours) FOR SUMMER AND WINTER

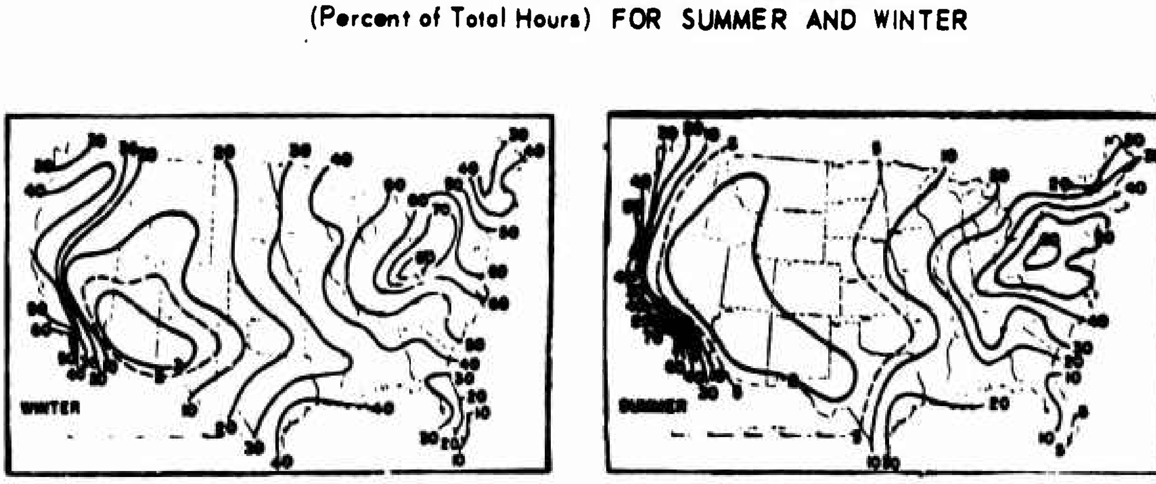


FIG. 4 DISTRIBUTION OF PERCENTAGE OF TIME THE VISIBILITY IS LESS THAN 10 km FOR SUMMER AND WINTER

layers of high-level temperature inversion, e.g., $4^{o}C$ measured in a vertical distance of a few meters, extending without appreciable changes in height for several tens of kilometers in the horizontal direction have been encountered (Lane, 1965). Such inversions are conducive to mirage formation when they are accompanied by extended visibility in the horizontal as well as in the vertical. A climatology of such inversions can be obtained from existing meteorological data.

4. Visual Characteristics of Light-Refraction Phenomena in the Cloud-Free Atmosphere

A. General

Light refraction as it occurs in the earth's atmosphere can be divided into *random* refraction and *systematic* or regular refraction (Meyer-Arendt, 1965). Random refraction is due to the small-scale (meters or less), rapid (seconds) temperature fluctuations associated with atmospheric turbulence, and is responsible for such phenomena as the scintillation of stars and planets, and the shimmer of distant objects. Systematic or regular refraction is the systematic deviation of a propagating wavefront by temperature gradients that are extensive in space (on the order of several kilometers or more) and persistent in time (on the order of an hour or more). Systematic refraction leads to the apparent displacement of a light source from its true position. The light source can be outside the atmosphere (astronomical refraction) or within the atmosphere (terrestrial refraction). Random and systematic refraction generally act simultaneously so that the associated effects are superposed.

Values of astronomical and terrestrial refraction computed for *average* atmospheric temperature structure are well documented. The angular difference between the apparent zenith distance of a celestial body and its true zenith distance (as observed from a position near sea level) is zero at the zenith but gradually increases in magnitude away from the zenith to a maximum of about 35 min. of arc on the horizon. Thirty-five minutes of arc is very nearly equal to the angle subtended by the sun's or moon's disc (30 min.), so that when these heavenly bodies appear just above the horizon they are geometrically just below it. Figure 5 shows average values of astronomical refraction as a function of zenith angle. The very large

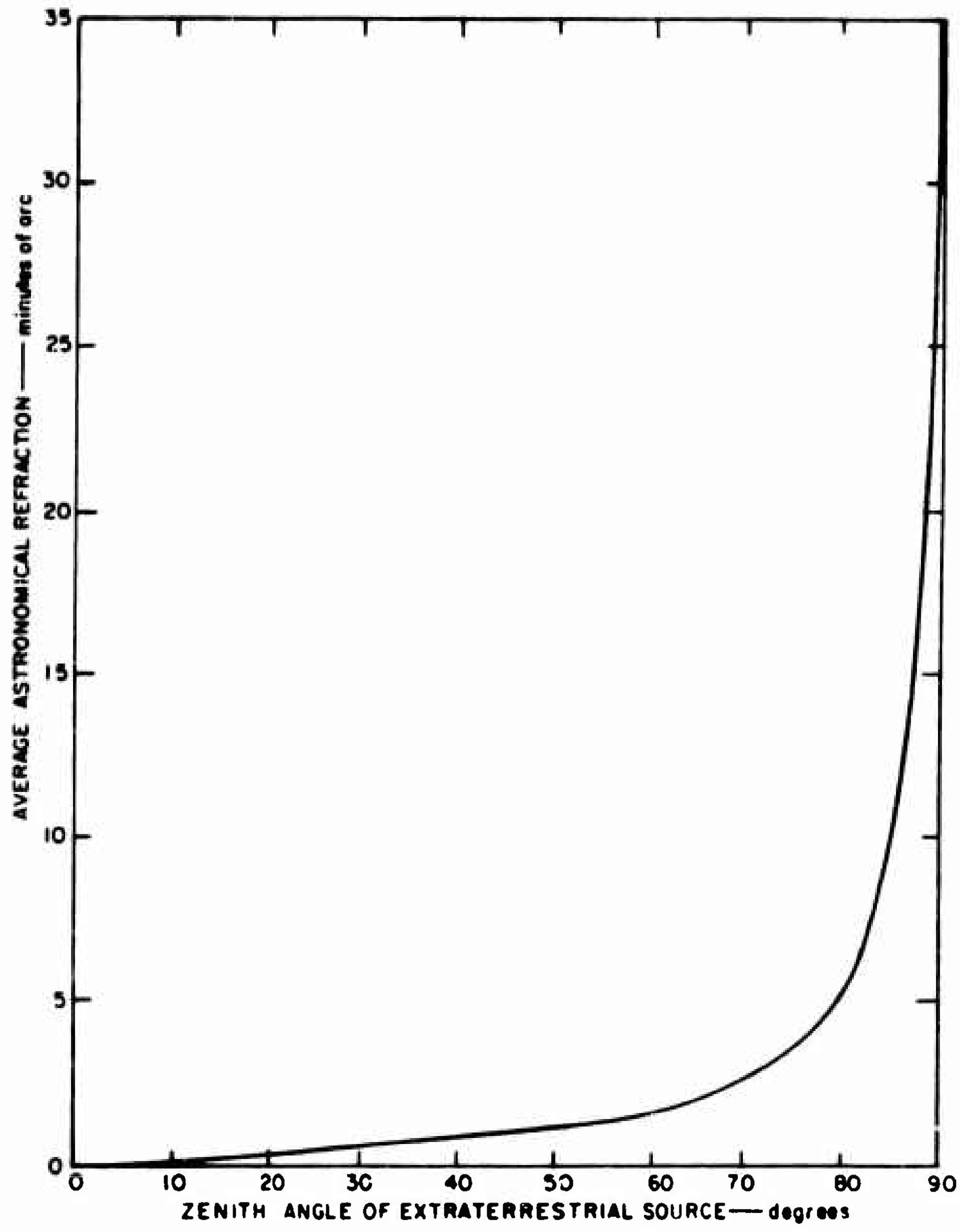


FIG. 5. ASTRONOMICAL REFRACTION vs. ZENITH ANGLE CORRESPONDING TO STANDARD ATMOSPHERE

increase in refraction toward the horizon causes frequently observed distortions of the sun's or moon's disc. Normally, the *differential* refraction between the point of the lower limb (touching the horizon) and the point of the upper limb (30 min. above the horizon) amounts to about 6 min., so that when on the horizon, the sun or moon appears to an earth-bound observer as an ellipse rather than a circle. Recent observations indicate that the setting sun or moon as seen from outside the earth's atmosphere also appears flattened due to refraction (Cameron, *et al.*, 1963). *Under abnormal atmospheric temperature conditions, the differential refraction can be so large that the rising or setting sun or moon appears in grossly distorted form* (O'Connell 1958).

Terrestrial-refraction angles have been computed as a function of zenith angle and altitude of the luminous source (Link and Sekera 1940; Saunders, 1963). Depending on height, refraction angles computed with reference to sea level vary from ≤ 5 sec. of arc at a zenith angle of 5° to ≤ 12 min. of arc at a zenith angle of 86°. Above 42 km refraction is negligible.

The importance of the seemingly small astronomical and terrestrial refraction on visual observations can be evaluated as follows. Resolving theory and practice have established that the human eye (which is a lens system) cannot resolve, separate clearly, or recognizably identify two points that subtend an angle to the eye of less than $1/16^{\circ} = 3.75$ min. (Tolansky 1964; Minnaert, 1954). Under standard atmospheric-temperature conditions, angular deviations due to astronomical and terrestrial refraction that are larger than 3.75 min. occur when distant light sources are less than about 14° above the horizon (zenith angle larger than about 76°). Hence, the effects of systematic atmospheric refraction on visual observations of a distant light source (point source) which is less than about 76° from the zenith can be considered negligible because the average human eye cannot clearly separate the source from its refracted image. *However, when the luminous point source is located at about 14° or less from the horizon, the location and appearance of the source as seen by a distant observer are those of its refracted image.* Close to the horizon, refraction becomes large enough to affect the visual observations of

extended sources. Thus, it is evident that the evaluation of observations of light sources that are close to the horizon requires knowledge of the characteristics of refracted images.

B. Characteristics of the Mirage

1. Geometry of Illumination and Viewing

When a luminous source is near the horizon, (i.e., near the horizontal plane of view of its observer) the optical path length through the atmosphere is maximum. In this case, systematic refraction is at a maximum and the visual effects can be large when layers of anomalous vertical temperature gradient are present. There are, however, important practical limitations as to how much the apparent position of a refracted image can differ from the true position of the source. Limits in the viewing geometry can be determined by Snell's law using limiting values of the optical refractive index.

Observations indicate that a temperature change of 30°C across relatively thin (<1 km) layers of temperature inversion or temperature lapse approximates the maximum change that can be expected (Ramdas, 1951). Thirty degrees Centigrade correspond to a refractive-index change of about 3×10^{-5} (Brunt, 1929). Combining this maximum change in the optical refractive index with the range of values listed in Table I, the following limits are suggested as the range of the refractive index (n) that can be expected in the lower cloud-free atmosphere.

$$1.00026 \leq n \leq 1.00029$$

Substitution of the upper and lower limit into the equation for total reflection gives

$$\sin\phi_c = \frac{1.00026}{1.00029} = 0.999970$$

and

$$\phi_c = 89.5^{\circ}$$

Hence, when a horizontal layer or boundary across which n has the assumed maximum variation of 1.00029 to 1.00026 is illuminated by a light source (direction of propagation from dense to rare), the angle of incidence has to exceed 89.5° (1/2° grazing angle) in order to get total reflection and a possible mirage image. *For all practical purposes, 0.5° can be considered as the near-maximum angle of illumination that will allow for formation of a mirage.* When the refractive index *decreases* with height

across the boundary and illumination is from below, the mirage image appears at a maximum angular distance of about 1° above the true position of the light source as illustrated in Fig. 6a . *Hence, one degree of arc must represent about the maximum angular distance that can be expected between the true position of the light source and its refracted image.* When the image appears above the true position of the source, the mirage is referred to as a *superior* mirage. When the refractive index increases with height and illumination is from above, an *inferior mirage* appears, i.e., the image lies below the true position of the source as shown in Fig. 6b. In terms of vertical temperature gradient, the superior mirage is associated with an inversion and the inferior mirage with a large temperature-lapse.

It is evident that *the presence of a layer of large temperature-gradient is necessary but not sufficient for mirage formation. A remaining requirement is the presence of light that illuminates the layer at grazing incidence.* The incident light can originate from a physical source such as sun, moon, or planet, or it can be skylight or sunlight reflected from the ground.

Whether the mirage is observed or not depends on the position of the observer with respect to the light source and the refracting layer. The planar geometry involved in a mirage observation can be illustrated by applying Eq. (3):

$$\frac{d\chi}{dz} = \frac{n_o \sin \phi_o}{\sqrt{n^2 - n_o^2 \sin^2 \phi_o}}$$

to a rectangular coordinate system in which the abscissa coincides with the ground. For simplicity it is assumed that $n^2 = n_o^2 - z$ (i.e., the refractive index, n , decreases with height), so that the solution to Eq. (3) represents a family of parabolas of the form

$$\chi = n_o^2 \sin 2\theta_o - 2n_o \sin \theta_o \sqrt{n_o^2 \cos^2 \theta_o - z}$$

(In applying Eq. (3), z represents az' where z' has units of height and a is the scale factor). The family of parabolas, sketched in Fig. 7, can be thought of as representing the light rays from a point source located at the origin of the coordinate system. Using the upper and lower limit

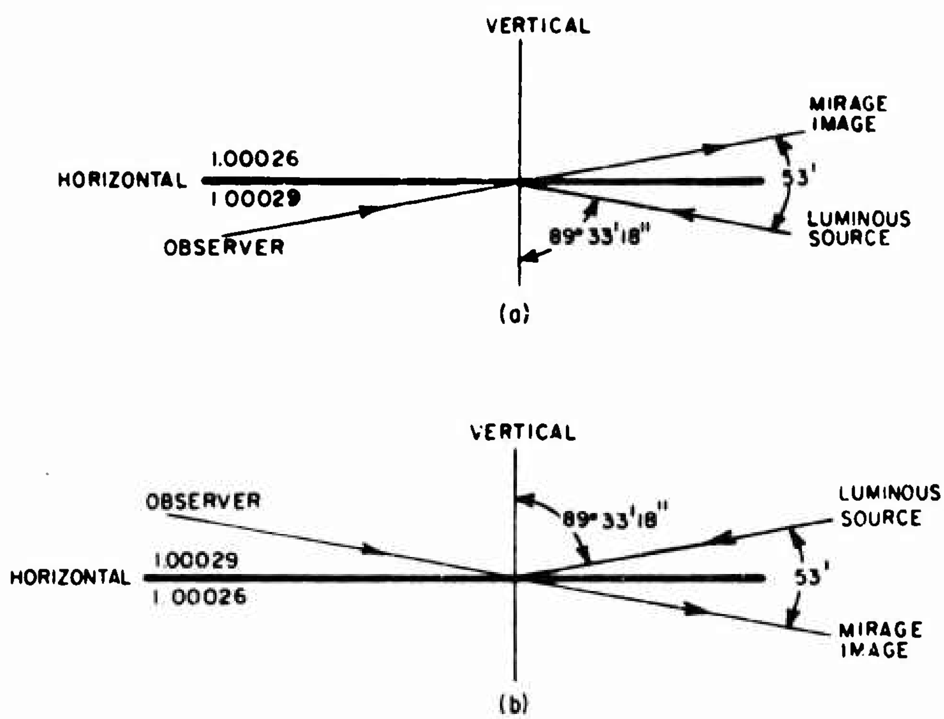


FIG. 6 LIMITING ANGULAR VIEWING GEOMETRY OF (a) SUPERIOR MIRAGE, (b) INFERIOR MIRAGE

of the optical refractive index, $n_o = 1.00029$ and $n = 1.00026$, the largest horizontal distance (D) is covered by the light ray for which $\theta_o = 89.5^o$ (angles are exaggerated in Fig. 7). All mirage images must be observed within this distance (see Fig. 7). D can be expressed in terms of the height (H) of the refracting layer as follows. For each member of the family of parabolas, z is maximum at the point where $(dz/d\chi) = 0$, i.e., at the point ($z = n_o \cos^2 \theta_o$, $\chi = n_o^2 \sin 2\theta_o$). Since each member is symmetric with respect to this point also,

$$\frac{D}{H} = \frac{2n_o^2 \sin 2\ (89.5^o)}{n_o^2 \cos^2 (89.5^o)} = 4 \tan 89.5^o$$

Hence, D $\approx$ 500H, i.e., all mirage images in this particular case are observed within a distance from the light source that is about 500 times the thickness of the refracting layer. For example, when the thickness of the refracting layer is 10 meters, no mirage observations of a particular object are likely beyond a distance of 5 km. At about 5 km an image of the object may appear at an elevation of about 0.5^o, while within 5 km images may appear at increasingly lower elevation angles until the eye can no longer clearly separate the image from the source.

The preceding discussion applies only to the case where the observer is located within, or at the boundary of, the mirage-producing layer, If the observer is some distance above or below the mirage-producing layer, mirages of much more distant objects may appear.

From the above, it is evident that principal characteristics of the optical mirage are the small elevation angles under which the phenomenon is observed ($\leq 1^o$) and the large distances (tens of kilometers) between observer and "mirrored" object that are possible. The geometry of the mirage explains why many observations are made on or near horizontally extensive, flat terrain such as deserts, lakes, and oceans and frequently involve images viewed through binoculars (oases, ships, islands, coastal geography). Furthermore, the above geometry illustrates that the duration of a mirage observation is critically dependent on whether or not the source and observer are in relative motion. For example, when the light source is moving in such a way that the angle of illumination, θ_o, oscillates around the critical angle, a stationary observer located at A in Fig. 7 may see a mirage image that alternately appears and disappears. On

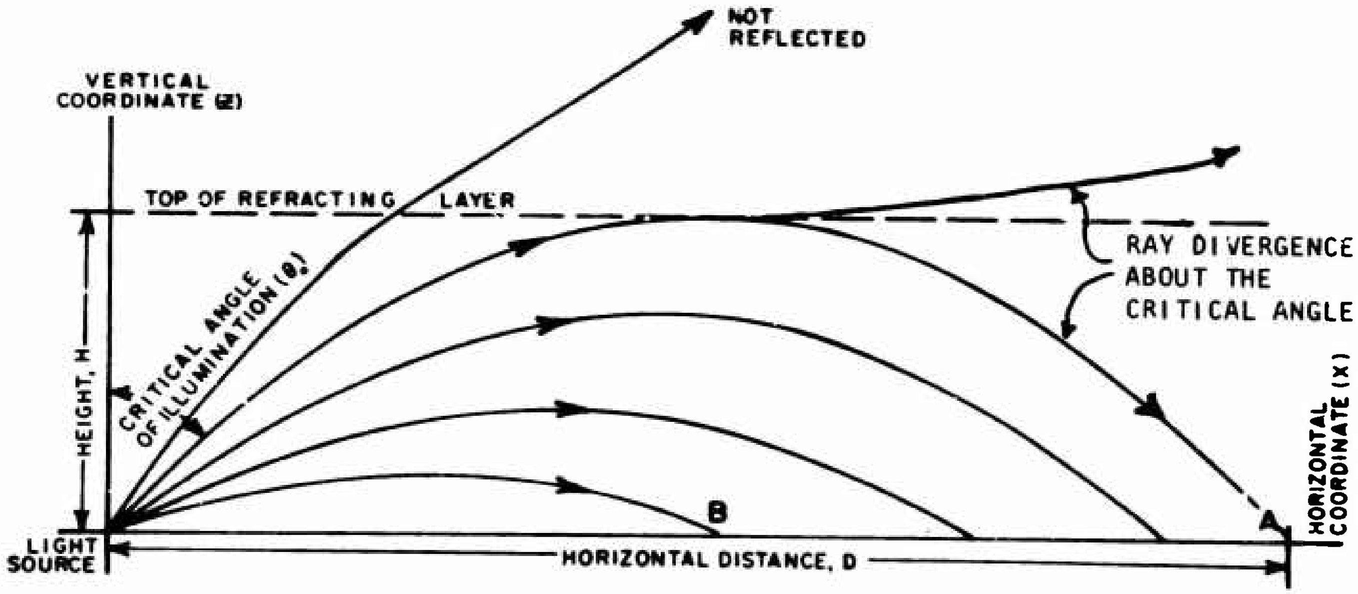


FIG. 7 PORTRAYAL OF LIGHT RAYS AS FAMILY OF PARABOLAS ($n^2 = n_0^2 - z$, $n_0 = 1.00029$, $n = 1.00026$, $\theta_0 = 89.5^{\circ}$)

the other hand, when the observer is moving relative to the source (from A to B in Fig. 7), the mirage image can change elevation, thereby creating an illusion of motion.

2. Number and Shape of Mirage Images

It has been recognized that systematic refraction of the light from a single source can lead to *multiple* mirage images the shapes of which can be complicated. The early observations by Vince (1798) and Scoresby (1820) included sightings of completely or partially inverted images of a single distant ship. From a coastal position on the English Channel, John Parnell (1869) observed *five* elevated images, all in a vertical line, of a lighthouse on the French Coast. All five images had different shapes. During their observations in Spain, Biot and Arago (1809) observed up to four elevated images of a distant (161 km) light signal. The images disappeared and reappeared intermittently and at times joined to form a narrow vertical column of light which subsequently separated into two parts, the lower part appearing red and the upper part appearing green. The above observations resulted from abnormal atmospheric light-refraction the observed images were distant, and in most cases detailed descriptions were made with the aid of binoculars.

Practically all theoretical and experimental investigations of optical mirages (e.g., Wollaston 1800; Hillers 1914; R. W. Wood 1911) have been concerned with demonstrating the number and shape of observed images. Tait's theoretical treatise and Wollaston's laboratory experiment can be considered classical examples. Tait's terrestrial-refraction model represents a horizontally stratified atmosphere, and a vertically finite refracting layer with a continuous change in refractive index. Under these assumptions the paths of light rays are represented by the solution to the differential equation:

$$d\chi = \frac{n_o \sin \phi_o}{\sqrt{n^2 - n_o^2 \sin^2\phi_o}} dz$$

where n can be expressed as a continuous function of height (z). Tait shows that *the number and shape of mirage images depend on the detailed structure of the refractive-index profile (temperature profile) within the refracting layer*. For example, the elevated mirage image of a distant

object becomes inverted when the refractive index in the upper part of the refracting layer decreases more rapidly with height than in the lower part. This "classical" explanation of image inversion is illustrated in Fig. 8. Shown are the paths of two light rays obtained from solving Eq. (3) for $n^2 = n_0^2 - z^2$. Thus, the refractive-index gradient $(\partial n/\partial z)$ in the upper part of the refracting layer is much larger than in the lower part. When the observer's eye is placed at the origin of the x, z coordinate system, *observed image-inversion arises from the crossing of light rays.*

Apparent vertical stretching (elongation, towering) of a luminous object due to refraction is illustrated in Fig. 9. For the sake of clarity, height and elevation angles are exaggerated. A horizontal refracting layer is assumed that is 10 meters thick and through which the refractive index (n) decreases with height (z) from 1.00029 to 1.00026 according to the relation $n^2 = (1.00029)^2 - z^2$. Hence, the refraction of a light ray increases with height. It can be shown that a 10-m-high luminous object placed at a horizontal distance of 2 km subtends an angle of approximately 26.5' at the origin. In the absence of the refracting layer the object would have subtended an angle of 16.8'. The apparent vertical stretching is brought about by the refractive-index profile; i.e., the increase in "bending' of the light rays with height elevates the upper part of the luminous source. *Vertical stretching can lead an observer to underestimate the true distance to the luminous object.* Vertical shrinking (stooping) of an extended object can be demonstrated similarly by assuming a refractive-index profile that is associated with a decrease of the gradient with height. In the case of vertical shrinking, the true geometric distance to the object involved is usually smaller than the apparent distance.

Many examples of image inversion, vertical stretching, and shrinking due to abnormal atmospheric refraction are given in *The Marine Observer*.

Tait's theoretical approach, the emphasis on the refractive-index profile, is basic to many other theoretical investigations of the mirage. For example, Wilhelm Hillers (1913) shows how two refracted images of a single light source can be formed when the profile in the refracting layer is such that the refracted rays are circular. Fig. 10 shows the

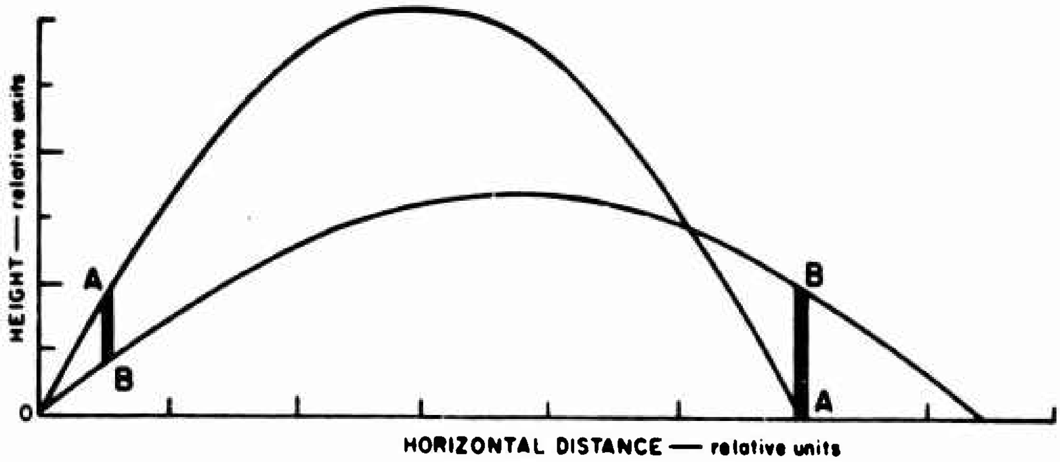


FIG. 8 CLASSICAL EXPLANATION OF IMAGE INVERSION (AB to BA) BY THE CROSSING OF LIGHT RAYS

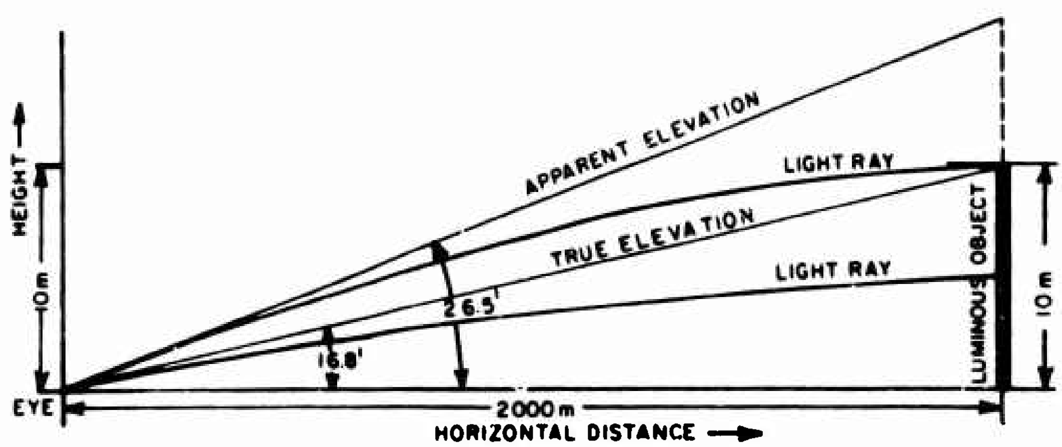


FIG. 9 ELONGATION OF LUMINOUS OBJECT DUE TO LIGHT REFRACTION

North Atlantic Ocean

S.S. Bristol City. Captain A. L. Webb, O.B.E. Sydney (C.B.) to Swansea. Observers, the Master and Mr. R. Whitman, 3rd Officer.

18th September, 1952, 2000 G.M.T. A vessel approaching end-on at 15 miles, with hull just visible, appeared to have elongated masts and funnel (Fig. 1). At

Fig. 1

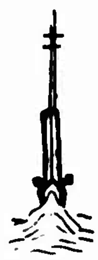


Fig. 2

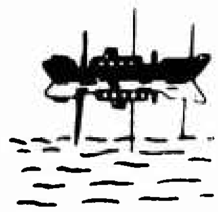


Fig. 3

10 miles the hull also became enlarged and the bow wave, very prominent (Fig. 2), appeared to move up and down the length of the stem. At 5 miles the vessel resumed normal shape. At the same time and position a second vessel, when 10 miles to the s'ward, suddenly developed an inverted image which lasted for 15 min before disappearing (Fig 3). A few minutes later the wake appeared, very prominent, resembling heavy surf which lasted another 10 min (Fig. 4). Before passing

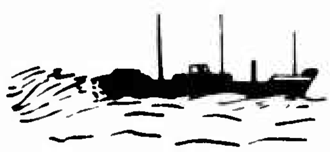


Fig. 4

Fig. 5

out of view the vessel appeared to take on a "block" shape (Fig. 5), only resuming its normal shape at brief intervals as the vessel dipped in the slight swell. Sea Temp. 53°F, air temp. 52°, wet bulb 50°. Calm sea, slight swell.
Position of ship: 48°32'N, 44°50'W.

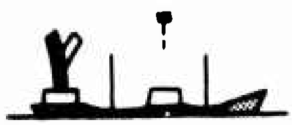
Note. This observation is also one of superior mirage and in Fig. 3 the inverted image is clearly seen. In Figs. 1 and 2 the vertical extension and distortion known as looming is well marked.

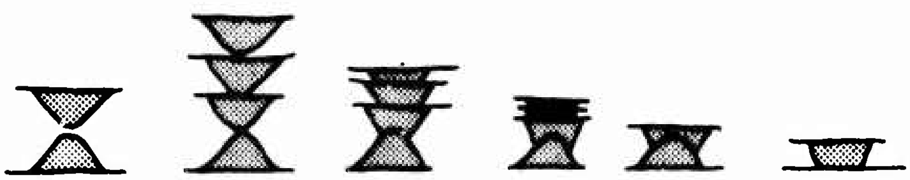
(Reproduced from *The Marine Observer*, Vol. 23, No. 161, p. 143, July 1953)

South Atlantic Ocean

S.S. Tenagodus. Captain W. Broughton. Cape Town to Algiers. Observers, Mr. J. J. Diston, Chief Officer, and Mr. J. F. Gristwood, 2nd Officer.

2nd March, 1955, 1730-1800 L.T. About one hour after leaving Cape Town abnormal refraction was noticed around the horizon from SW. through N. to E. A large tanker, 8 miles distant on the port beam, was considerably distorted; the funnel was greatly elongated and appeared taller than the masts, and swayed occasionally. The radar scanner appeared suspended well above the ship. On the starboard bow, 28 miles distant, a hill 280 ft high at Ysterfontein Point was observed to have an inverted image. A few minutes later there were three inverted images; these gradually telescoped until the hill appeared as a block. Temperatures: air 66°F, sea 59°. Slight sea, low swell. Position of ship: 33°49'S., 18°16'E.





(Reproduced from *The Marine Observer*, Vol. 26, No. 172, April 1956)

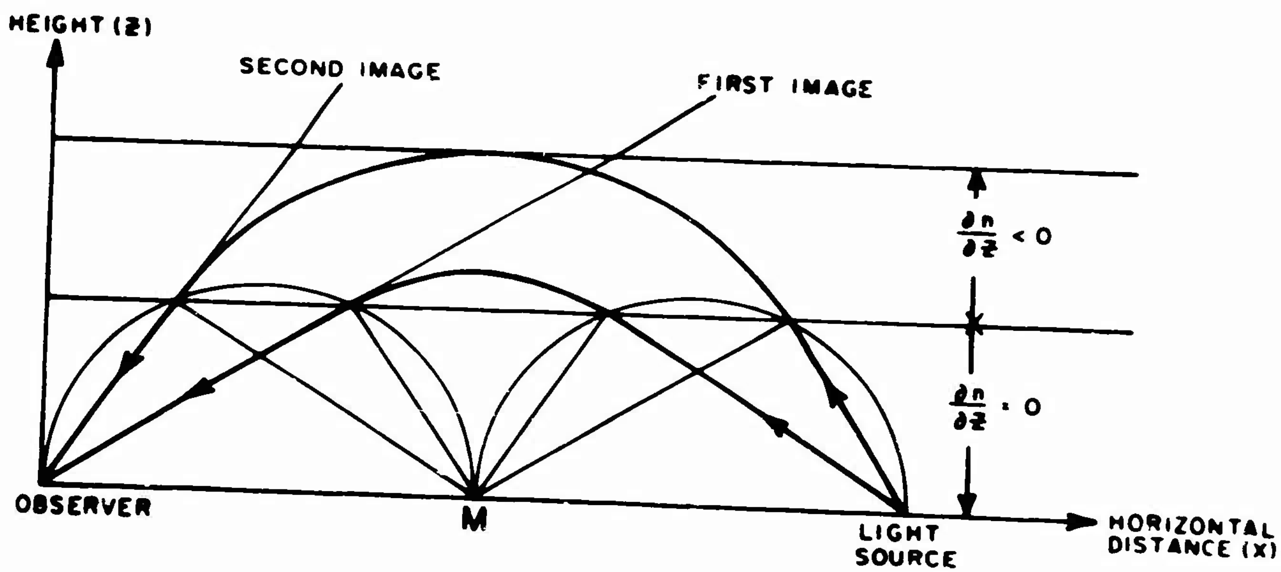


FIG. 10 GEOMETRY OF SPECIAL CASE IN WHICH REFRACTION GIVES TWO SEPARATE IMAGES OF A SINGLE LIGHT-SOURCE

geometry of this special case. The refracting layer lies above the observer and the distant light source. Refraction below the refracting layer is assumed negligible, i.e. , light rays are rectilinear. When the light rays penetrating the refracting layer are circles concentric about M, two separate rays emanating from the light source reach the observer's eye and all rays imtermediate and outside these two fail to be tangent to a concentric circle. Consequently, the observer views two separate images. An example of three observed images of a distant hill is shown in the figure on page 1026 in an excerpt from *The Marine Observer*.

Tait's approach cannot be applied indiscriminately to all mirage phenomena because integration of Eq. (3) is restricted to a selected range of refractive index profiles. Furthermore, the effect of the earth's curvature is excluded so that only mirage phenomena associated with not-too-distant objects can be considered. Hence, Tait's model cannot explain mirage observations associated with extraterrestrial sources such as the sun or the moon.

Alfred Wegener (1918) has developed an atmospheric-refraction model that explains distorted images of the sun, moon, planets, or stars that are often observed near the horizon. Wegener assumes a spherically stratified atmosphere and reduces the refracting layer to a refracting boundary or surface of total reflection. Wegener demonstrated that when the refracting boundary lies above the observer and the sun is on the horizon, the boundary refracts the solar light rays in such a way that the observer views two separate images of the solar disc, a flattened upper image and a distorted lower image. Fig. 11 shows the successive form of the two images for a setting sun or moon in the presence of a 7^{o} temperature-inversion layer 50 m above the observed as computed by Wegener. The degree of deflection of the incoming light rays and consequently the degree of distortion of the solar disc depends on the refractive-index change or temperature change across the reflecting boundary. When the temperature change is small, only a single distorted image of the solar disc appears. When the change across the boundary is

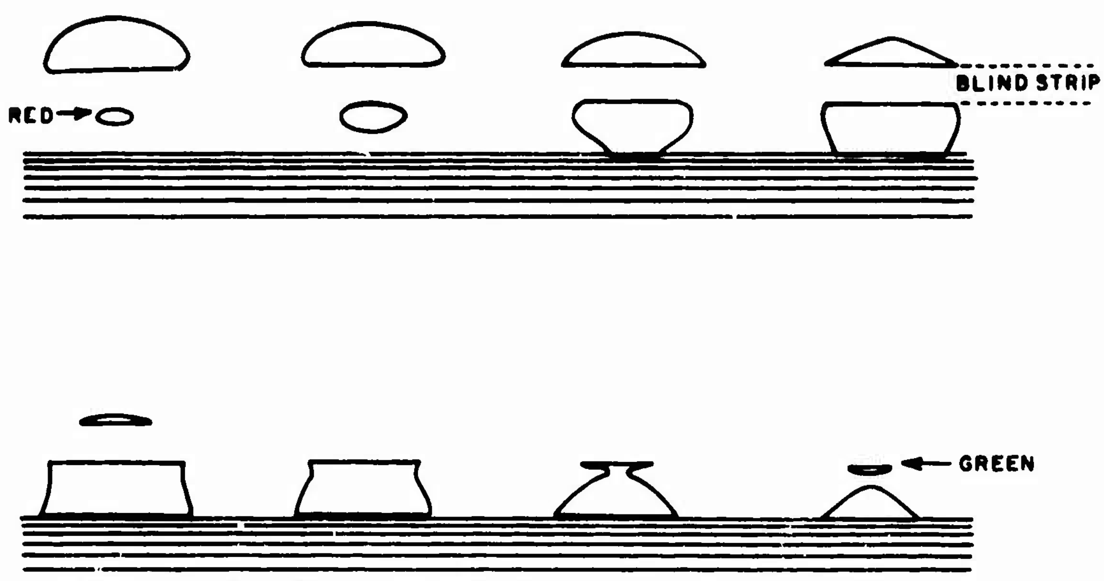


FIG. 11 SUCCESSIVE IMAGES OF SETTING SUN OR MOON DURING CONDITIONS OF MIRAGE

very large only the the flat upper part of the "split" solar image is seen, so that the setting sun appears to vanish above the horizon. When the atmosphere is highly stratified, i.e., when several horizontal refracting boundaries are present, the setting sun can appear like a Chinese Pagoda or like a stack of discs. The refracted images of the setting sun computed by Wegener's model agree closely with those photographed and described by D. J. K. O'Connell (1958) in connection with a study of the green and red flash phenomena.

Wegener's model is not restricted to luminous sources outside the earth's atmosphere. It can be applied to distant terrestrial objects such as mountains from which emitted light rays are at grazing incidence to the top of the refracting boundary. Wegener's model of atmospheric refraction illustrates the characteristics that are basic to many spectacular risings or settings of sun, moon, or planet. Following are three accounts of such abnormal atmospheric-refraction phenomena as given in *The Marine Observer*.

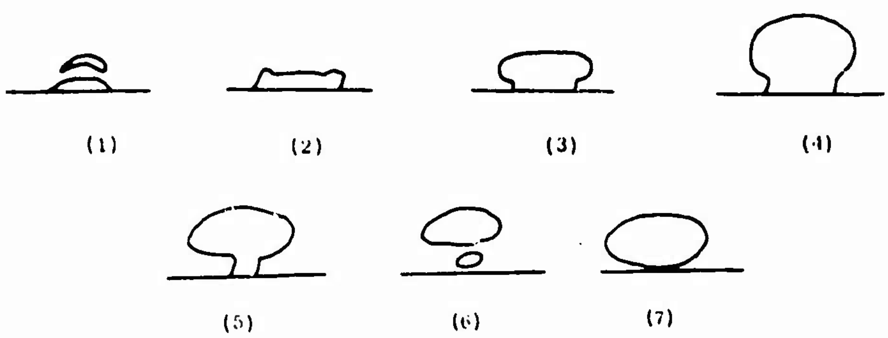
The atmospheric-refraction models of Tait and Wegener quantitatively explain the basic characteristics of the most commonly observed mirage-images. Other theoretical investigations are available that discuss various special aspects. For example, the theory of the superior mirage by Odd Haug explains the appearance of up to four images from a single source. Wilhelm Hillers treats the special case of a lateral mirage, i.e., the refraction of light when the refractive-index gradient is horizontal, as may be the case along a wall heated by solar radiation. Koji Hidaka and Gustav Forster discuss the theory of refraction when the surfaces of constant density in the atmosphere are somewhere between horizontal and vertical. Together, these theoretical models explain adequately the varying ways in which a mirage image can appear to an observer. Currently, there is no *single* model with a numerical solution to all aspects of the mirage.

ABNORMAL REFRACTION

Off coast of Portugal

M. V. *Australind*. Captain J. F. Wood. Port Said to Bremen. Observer, Mr. D. Ewan, Chief Officer.

27th April, 1950, 0546-0549 G.M.T. The accompanying sketches picture the sequence of shapes assumed by the sun as a result of refraction. After



clearing the horizon the sun slowly regained its normal proportions and at an altitude of $1\frac{1}{2}^\circ$ no refraction was apparent. No land was visible near the phenomenon. Wind N, force 4. Barometer 1020·3 mb., air temp. 58°F. Sky cloudless.

Position of ship: Latitude 38° 04′ N., Longitude 9° 24′ W.

(Reproduced from *The Marine Observer*, Vol. 21, No. 152, p. 80, April 1951)

ABNORMAL REFRACTION
North Atlantic Ocean

O.W.S. *Weather Recorder*. Captain A. W. Ford. At Ocean Weather Station A. Observer, Mr. J. Ballantyne, 3rd Officer.

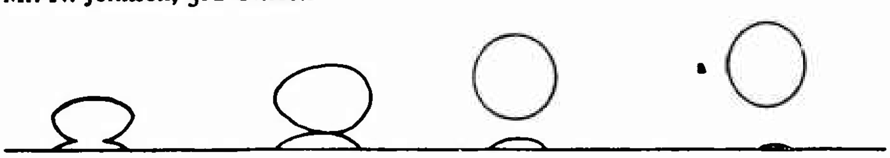
5th May, 1955, 2220–2240 G.M.T. Towards sunset abnormal refraction was observed, and for a while two suns were visible. A false sun was seen for half its

diameter on the horizon, and touching the real sun above. The real sun was partly obscured by cloud. The false sun persisted for 3 or 4 min after the real sun had set. A vertical ray with reddish coloration extended to about 4° above the real sun.

(Reproduced from *The Marine Observer*, Vol. 26, No. 172, April 1956)

ABNORMAL REFRACTION
English Channel

M.V. *Timaru Star*. Captain H. W. McNeil. London to Curaçao. Observer, Mr. N. Johnson, 3rd Officer



4th January, 1956. While proceeding down the English Channel at 0800 G.M.T., shortly after sunrise, the sun was observed to have a distorted appearance (sketch 1). By 0810 while the sun continued to rise a false "sun" began to set. Two minutes later there was a distinct gap between the true sun and the false and by 0814 the false sun was no longer visible. In the area of the rising true sun the sky was clear and a bright orange in colour. A phenomenon similar to sketch 2 was observed at sunset on the same day.

Position of ship: 50° 05′N., 02° 04′W.

(Reproduced from *The Marine Observer*, Vol. 27, No. 175, p. 13, 1957)

3. Effects from Focussing and Interference

A recent theoretical and experimental investigation of the optical mirage is presented by Sir C. V. Raman (1959). Sir C. V. Raman demonstrates that multiple, inverted images of a single object can arise from interference and focussing of the incident and reflected wavefronts near the boundary of total reflection. Raman's work, which is entirely based on wave theory, suggests the interaction of wavefronts within a refracting layer as a mechanism in mirage formation.

The occurrence of focussing and interference in situations that give rise to mirage, examined specifically by Raman, is also evident from various investigations based on geometrical optics. For example, the crossing of light rays mentioned in connection with image inversion implies interference of wavefronts at the points of intersection.

The visual effects from focussing and interference must be considered in particular when plane-parallel radiation (radiation from a very distant source) is incident on a layer of total reflection. In this case, there is a constant crossing of light rays within a relatively narrow region of the refracting layer, as illustrated in Fig. 12 (for the sake of clarity, height and elevation angles are exaggerated). In Fig. 12, a circular collimated light-beam of diameter A is incident on the lower boundary of a temperature-inversion layer at angle equal to or exceeding the critical angle for total reflection. Interference of the incident and reflected wavefronts occurs in a selected layer near the level of total reflection. This layer, shaded in Fig. 12, has a maximum thickness B, which is dependent on A. In the absence of absorption, the amount of radiant energy, flowing per unit time through πA^2 equals that flowing through πB^2. When B is less than A, the energy density at B is larger than at A, so that the brightness of the refracted light beam increases in the layer of interference.

An example of the ratio of A to B can be given with the aid of Eq. (3). It is assumed that the optical refractive index through the inversion layer varies from $n_o = 1.00029$ to $n = 1.00026$ according to $n^2 = n_c^2 - z$. When the angle of incidence is near the critical angle for total reflection ($\theta_o \cong 89.5^o$), the light rays within the inversion layer are parabolas and

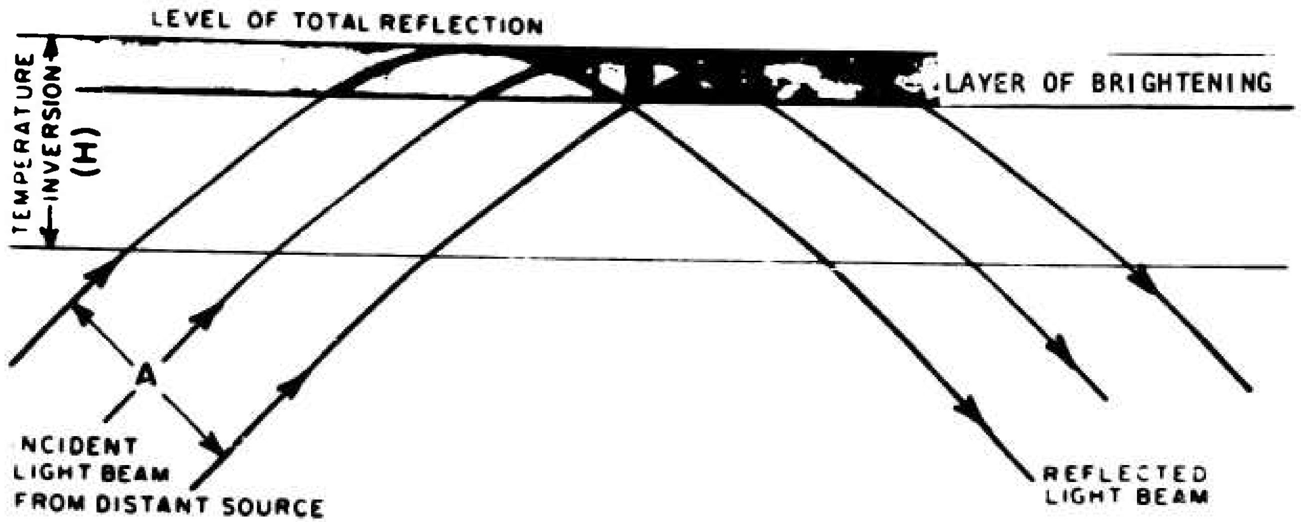


FIG 12 INCREASE IN ENERGY DENSITY NEAR UPPER BOUNDARY OF HIGH-LEVEL TEMPERATURE INVERSION

the level of total reflection coincides with the upper boundary of the inversion layer. Under these conditions, it can be shown that

$$\frac{B}{A} = \frac{A}{16H}$$

where H is the thickness of the temperature-inversion layer. When the diameter A of the incident light beam is less than 16H, B is less than A and a brightening or focussing occurs near the top of the inversion. When the angle of incidence of the light beam is larger than the critical angle, $\backsim 89.5^{\circ}$, the level of total reflection lies below the upper boundary of the inversion layer. In this case, brightening can still occur near the level of total reflection, but the restrictions on the required beam-diameter become rather severe. The above example, based on a special case, demonstrates that sudden brightening can be encountered near the upper boundary of a refracting layer *when optical mirages are associated with a refracting layer that is thick with respect to the diameter of the incident light beam from a distant source and when the angle of incidence is near the critical angle.*

Observations of the brightening phenomenon must be considered rare in view of the selective location of its occurrence within the temperature-inversion layer and the requirement of plane-parallel incident radiation. Upper-level inversions seem most likely to produce the phenomenon. Some photographs showing apparent brightening of "spike" reflections on the edge of the setting sun are shown in O'Connell(1958, c.f., p. 158).

Microscopic effects due to interference of wavefronts within the area of brightening are illustrated in Fig. 13. Wavefronts are indicated rather than light rays. Unless absorption is extremely large, light rays are normal to the wavefront. A train of plane-parallel waves is assumed incident on the lower boundary of a refracting layer in which the refractive-index decreases with height. When the angle of incidence equals the critical angle, the incident waves are refracted upon entering the refracting layer and are totally reflected at the upper boundary The crests and troughs of the waves are indicated by solid lines and dashed lines, respectively. At the upper boundary, the wavefronts of the incident and reflected waves converge to a focus. The focus is called a cusp. The upper boundary of the refracting layer resembles a caustic,

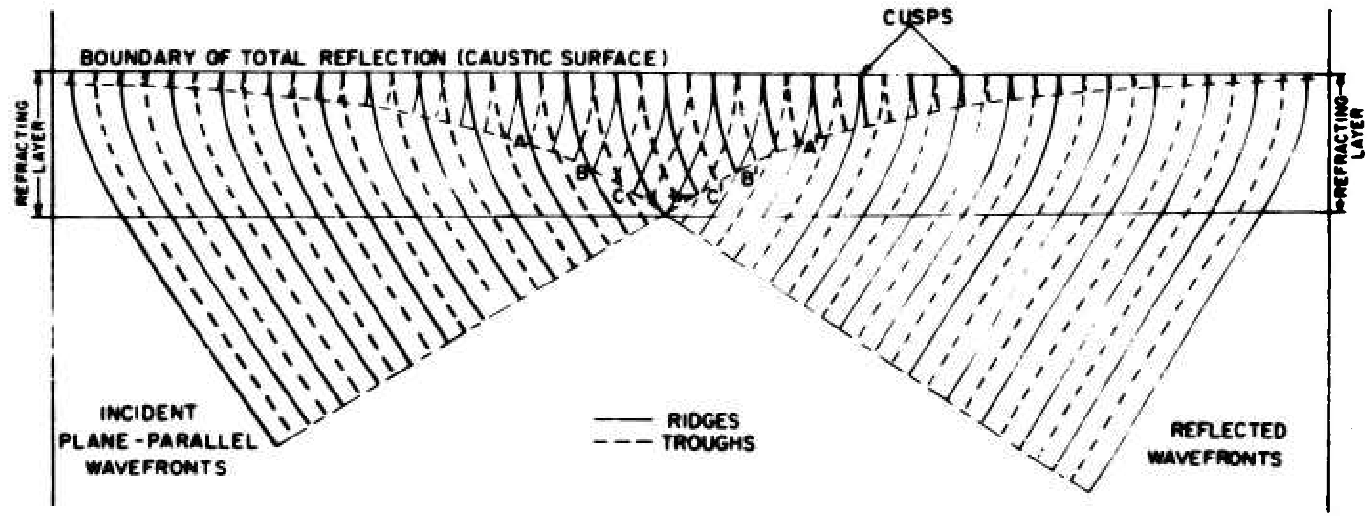


FIG. 13 SIMPLIFIED CONSTRUCTION OF WAVEFRONTS IN REGION OF INTERFERENCE AND FOCUSSING

i.e., an envelope of the moving cusps of the propagating wavefronts. Because of the focussing of wavefronts, a large concentration of radiant energy is usually found along the caustic (see Raman, 1959). In the area where the incoming and outgoing wavefronts interact, destructive interference is found along AA' and CC' (troughs meeting crests), while constructive interference is found along BB' (incident and reflected waves have similar phase). Hence, brightness variations can be expected in the interference layer, as demonstrated by Sir C. V. Raman (1959). To what extent the microscopic effects from interference and focussing can be observed under actual atmospheric conditions of mirage is not known. Undoubtedly, the proper relation between refracting layer and distant light source must be combined with an observer's position near the upper boundary of the refracting layer. If the dark and bright bands in the area of interference can be observed, the observer could easily get the impression that he is viewing a rapidly oscillating light or a light that is drawing near and moving away at rapid intervals. Nighttime observations by airplane are most likely to provide proper evidence of this effect.

Currently, the focussing and interference effects are the least explored and consequently the least discussed of the various aspects associated with optical mirage.

4. Refractive Separation of the Color Components of White Light (Color Separation)

Due to the wavelength dependence of the optical refractive index, systematic refraction of white light leads to a separation of the composing colors. *Visible effects of color separation are most frequently associated with astronomical refraction.* In this case, the light enters the atmosphere at an upper boundary where n approaches unity for all wavelengths. At an observation site near sea level n is wavelength-dependent, so that from the upper boundary of the atmosphere to the observation site the individual color components are refracted at different angles. The basic composing color of white light may be assumed to be red (24%), green (38%), and blue-violet 38%); the red is refracted less than the green, while the green is refracted less than the blue-violet. The visual effects of color separation depend on the zenith

angle of the extraterrestrial light source. When a white light source is more than 50° above the horizon, the color separation is simply too small to be resolved by the eye. Close to the horizon it can be observed only in the case of very small light sources. The principle of color separation in astronomical refraction is illustrated in Fig. 14. The light from an extended source enters the top of the atmosphere and is separated with respect to color in the order red, green, blue, and violet. A bundle of light rays of diameter D can be selected for which all colors, upon refraction, converge at O. Hence, an observer at O sees the entire color mixture as white. When the extended source has a diameter larger than D, an area rather than a single point of color blending is formed. However, when the diameter of the source becomes less than D, the point of color convergence, O, recedes from the location of the observer. Now the observer begins to see a gradual refractive separating of color such that red tends to lie below green, and green tends to lie below blue-violet (see Fig. 14).

The diameter of the light beam from a given extraterrestrial source *decreases* with respect to an earth-bound observer, with increasing distance from the zenith, as illustrated in Fig. 14. Thus, when the zenith angle increases, the *apparent* diameter D of the light source decreases rapidly to a minimum value on the horizon. Hence, the chance of having a light source of diameter less than D is greatest on the horizon. *Therefore, color separation is observed most frequently on the horizon, when the light source is reduced to a bright point like a star or a minute portion of the solar or lunar disc.* A prominent example of the visible effects of color separation is the so-called Green Flash. This phenomenon is sometimes observed when the sun disappears in a clear sky below a distant horizon. The last star-like point can then be seen to change rapidly from pale yellow or orange, to green, and finally, blue, or at least a bluish-green. The vividness of the green, when the sky is exceptionally clear, together with its almost instant appearance and extremely short duration, has given rise to the name "green flash" for this phenomenon.

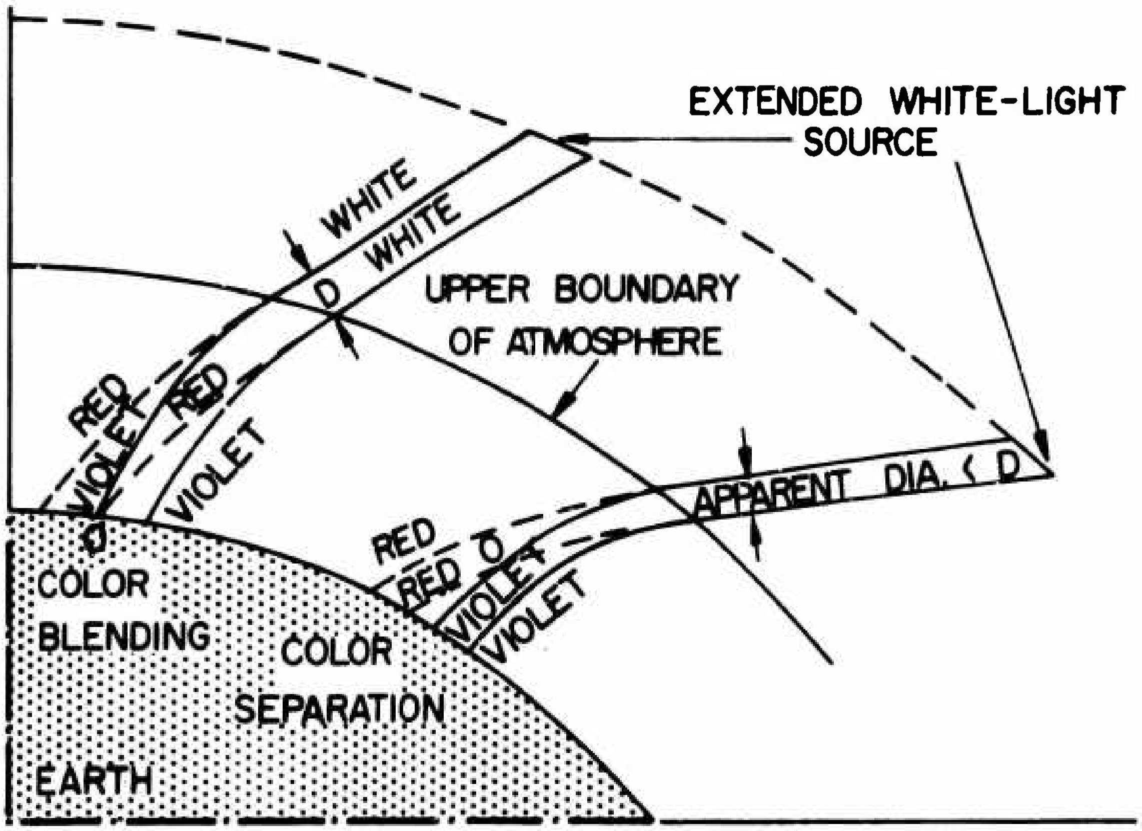


Fig. 14 Refractive Color Separation as a Function of Zenith Angle

The same gamut of colors, only in reverse order, occasionally is seen at sunrise. The observations of the Green Flash require an unusually clear atmosphere such that the sun is yellowish, and not red, as it begins to sink below the horizon. A red setting sun means that the blue and green portions of the spectrum are relatively strongly attenuated by the atmosphere and hence indicates that conditions are not favorable for seeing the greenish segment. Thus, the meteorological conditions required for observing color separation are even more stringent than those required for observing optical mirages. Examples of color separation associated with astronomical refraction are given on the following page in excerpts from *The Marine Observer*.

In terrestrial refraction the composing colors of white light are very seldom separated to the extent that the effects can be observed with the naked eye. When the wavelength dependence of the refractive index is put back into Eq. (4),

$$\frac{\partial n}{\partial z} = 77.5\left(1 + \frac{5.15 \times 10^{-3}}{\lambda^2} + \frac{1.07 \times 10^{-4}}{\lambda^4}\right)10^{-6}\,\frac{P}{T^2}\left(\frac{-3.4^{\circ}\mathrm{C}}{100\ \mathrm{m}} - \frac{\partial T}{\partial z}\right).$$

Hence, for a given temperature inversion, the refractive index (n) decreases somewhat faster with height (z) for $\lambda = 0.4\mu$ (blue) than for $\lambda = 0.7\ \mu$ (red), so that the blue rays are refracted more than the red rays. However, the difference is generally too small to be resolved by the eye. Only under very special conditions can a visible effect be imagined. For example, when a 100-m-thick inversion layer is assumed to be associated with a $\Delta T = 30^{\circ}$C, the change of the refractive index for blue light and red light is respectively, $\Delta n(0.4\ \mu) \simeq 3.01 \times 10^{-5}$ and $\Delta n(0.7\ \mu) = 2.93 \times 10^{-5}$. When the optical refractive indices at the lower boundary of the inversion are $n_o(0.4\ \mu) \approx 1.000282$ and $n_o(0.7\ \mu) = 1.000275$ (corresponding to $P = 1013.3$ mb and $T = 15^{\circ}$C), values at the upper boundary are $n_o(0.4\ \mu) \simeq 1.000252$ and $n(0.7\ \mu) \simeq 1.000246$. When white light is incident at the lower boundary of the inversion at an angle ϕ_o such that

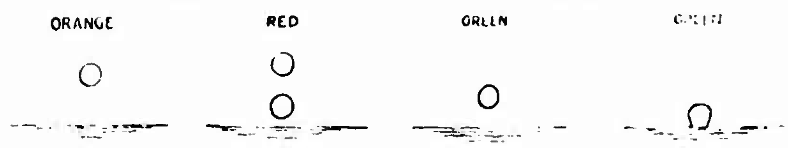
$$\frac{1.000246}{1.000275} > \sin\phi_o > \frac{1.000252}{1.000282}$$

then the blue rays are totally reflected by the inversion layer but the red rays are transmitted. Hence, for $\phi_o \approx 89^{\circ}\ 33'\ 30''$ the blue rays are totally reflected, and for $\phi_o \approx 89^{\circ}\ 33'\ 54''$ the red rays are totally reflected. The visible effects of color separation that can arise when ϕ_o fluctuates from

SETTING OF THE PLANET VENUS
Indian Ocean

S.S. *Strathnaver*. Captain I. M. Sinclair. Australia to London. Observer, Mr. J. C. Vint, Supernumerary 2nd Officer.

6th December, 1957 at 2105 S.M.T. The accompanying sketch illustrates the



changes observed in the planet as it was setting. Prismatic binoculars were used to observe the phenomena.

Position of ship: 01° 40′N., 84° 32′E.

Note. The phenomena seen at the setting of the bright planets Venus and Jupiter vary considerably on different occasions and are always interesting. Sometimes no double images occur. When they are seen, they may be of the same or different colours. The green colour is not always seen before the instant of setting, as it was in this observation.

(Reproduced from *The Marine Observer*, Vol. 28, No. 182, p. 194, Oct. 1958)

GREEN FLASH

South Atlantic Ocean

M.V. *Drina*. Captain F. J. Swallow. Las Palmas to Buenos Aires. Observer, Mr. W. M. Wheatley, Chief Officer.

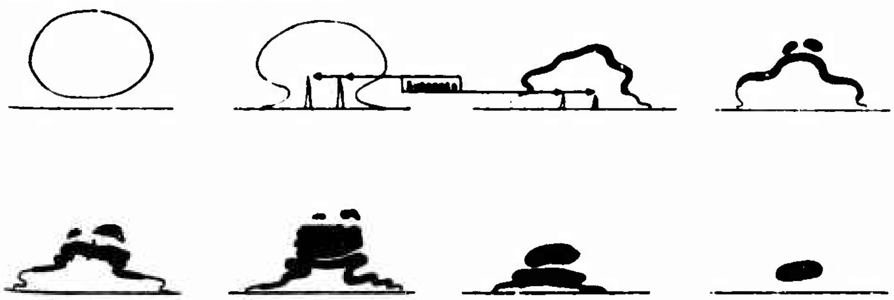
28th January, 1956. At sunset the sun, when half a diameter above the horizon, became lemon-coloured, although the shape remained normal. The final visible segment of the sun turned to a vivid electric blue. Visibility excellent. The sky after sunset was colourful with great clarity of cloud shapes and colours. Cloud 3/8 Cu and Ac.

Position of ship: 18° 28′s., 38° 28′w.

Note. The name of this phenomenon at sunset or sunrise is the "green flash", green being the colour most usually seen. It would not be practicable to name it according to the colour observed, as these comprise various shades of green and blue, also purple or violet. We have had more observations of blue, purple or violet flashes in recent years. While these colours are admittedly much less frequently seen than various shades of green, it does appear that they are not as rare as was formerly supposed; a probable explanation of this is that more observers are now watching for the phenomenon.

Red Sea

M.V. *Gloucester*. Captain D. A. G. Dickens, R.N.R. Jeddah to Suez. Observer, Mr. R. E. Baker, Chief Officer.



19th February, 1956. Abnormal refraction was observed as the sun set, apparently shaped as shown in the sketches. The green flash was seen all the time the upper half of the sun was disappearing, approximately 30 sec; not only the detached pieces appeared green but the edges of the main body as well.

Position of ship: 22° 08′N., 38° 25′E.

North Pacific Ocean

S.S. *Pacific Northwest*. Captain F. H. Perry. Panama to Los Angeles. Observer, Mr. W. P. Crone, 4th Officer.

29th January, 1956. Half a minute before setting at bearing 262° Venus appeared to turn bright red, becoming orange again just before setting. At the moment of setting at 0345 G.M.T. there was an emerald green flash of 1 sec duration. This observation was made with the aid of binoculars. Cloud 2/8.

Position of ship: 24° 55′N., 112° 44′W.

(Reproduced from *The Marine Observer*, Vol. 27, No. 175, p. 15, Jan. 1957)

GREEN AND RED FLASHES

South Pacific Ocean

M.V. *Cambridge*. Captain P. P. O. Harrison. Wellington to Balboa. Observers, the Master, Mr. P. Bower, Chief Officer, and Mr. L. Money, 4th Officer.

2nd May, 1957. When the sun rose at 0700 S.M.T. a green flash was plainly seen. There was a bank of cumulus whose base was one sun's diameter above the horizon and as the sun disappeared behind the cloud a red flash occurred lasting fully 3 sec.

Position of ship: 38° 51′S., 175° 10′W.

(Reproduced from *The Marine Observer*, Vol. 28, No. 180, p. 77, April 1958)

SETTING OF THE PLANET JUPITER

Gulf of Mannar

S. S. *Sirsa*. Captain N. Maguire. Rangoon to Cochin. Observer, Mr. J. Richardson.

3rd December, 1950, 1755 G.M.T. Jupiter on setting showed a red spot on the side nearest to the horizon. The spot was visible through binoculars and telescope but not to the naked eye. The sky was clear in the vicinity and the phenomenon was visible from the time that the planet was 20 above the horizon.

Position of ship: 7° 40′ N. 77° 47′ E.

Note. When abnormal refraction is present the light of stars or planets near the horizon tends to be elongated into a short spectrum with the red nearest the horizon and the green and blue farthest from the horizon. Many varieties of phenomena result, especially in the case of the bright planets Jupiter and Venus; these are more often seen with binoculars than with unaided vision. At times the planet may appear double, one red and one green, or the colour of the planet may change from red to green. In cases of extreme refraction the planet may be seen to "swim" about with a lateral motion, accompanied by changes of colour, usually from red to green, with momentary returns to the normal colour of the planet. The green flash of sunrise or sunset is an example of the same thing; the uppermost green image of the sun's limb is visible for a fraction of a second after the sun has set.

(Reproduced from *The Marine Observer*, Vol. 21, No. 154, p. 214, Oct. 1951)

89^{o} 33' 30" to 89^{o} 33' 54", are illustrated in Fig. 15. It is assumed that the white-light source is far away so that the incident rays are near parallel. For $\phi \approx 89^{o}$ 33' 30" the blue rays are totally reflected by the red rays penetrate the upper boundary of the inversion. When ϕ_o varies from 89^{o} 33' 30" to 89^{o} 33' 54" the red rays are alternately transmitted and totally reflected. Hence, an observer near A may see an elevated image that is alternately bluish and white, while an observer at B may see a reddish image that disappears and reappears. The small fluctuation in ϕ_o can be produced by atmospheric turbulence or short-period changes in the lower boundary of the inversion. Color changes from red to green that frequently occur when distant lights are observed can be similarly explained. In general, visible color separation is the result of a combined action of random and systematic atmospheric refraction.

Thus, unusual color effects that can be observed with the unaided eye can be associated with mirage phenomena. Occurrence of these effects, however, must be considered unusual in view of the special set of circumstances required for their development.

5. Effects from Atmospheric Scintillation

Scintillation defines the *rapid* variations in apparent brightness, position, or color of a distant luminous source when viewed through the atmosphere. If the object lies outside the earth's atmosphere, as in the case of stars and planets, the phenomenon is termed astronomical scintillation; if the luminous source lies within the atmosphere, the phenomenon is termed terrestrial scintillation.

Scintillation occurs when small-scale (meters or less) inhomogeneities in atmospheric density interference with a propagating wavefront for a short duration of seconds or minutes. Such inhomogeneities are generally associated with turbulance and convection. Turbulence convection are most apparent in atmospheric layers close to the earth's surface where they develop under proper conditions of solar heating, wind velocity, and terrain. However, they can occur also at high levels in the atmosphere. Scintillation has been found associated with atmospheric layers near the tropopause (30,000 to 40,000 feet).

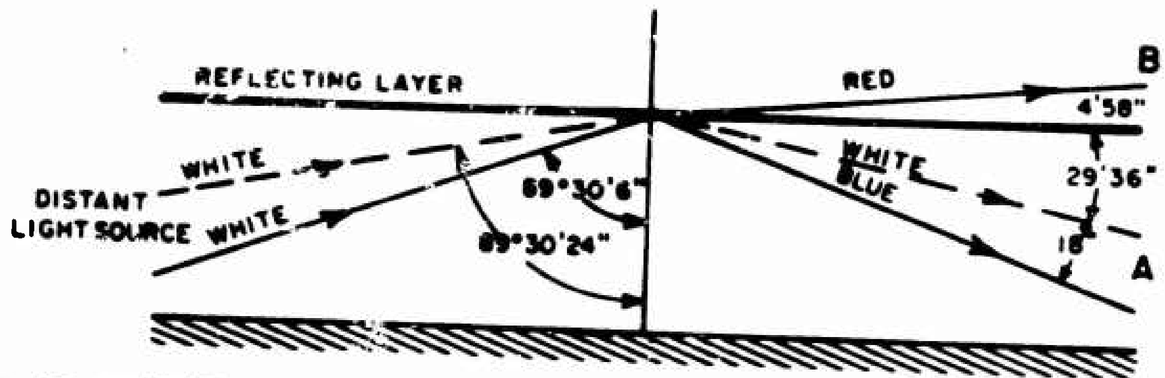


FIG. 15 GEOMETRY OF ILLUMINATION AND VIEWING FOR A SPECIAL CASE OF REFRACTIVE COLOR SEPARATION

Rapid fluctuations in brightness(scintillation in its strictest sense) are observed most frequently. The reason for this may be that, on the average, the time interval between moments of nearly maximum brightness is around 1/10 of a second, a value that coincides with the frequency to which the human eye is most sensitive. Higher frequencies of scintillation do occur (30 to 50 per second), but their significance is restricted to measurement made by means of optical equipment such as telescopes. The apparent brightness fluctuations of a distant source may be so intense that an observer sees the light source as "flashing on and off."

Fluctuations in position are often referred to as "shimmer", "dancing", or "wandering", and involve the apparent jerky or continuous movement of an image about a mean point. Observations of this phenomenon are not as common as observations of intensity fluctuations. Under standard atmospheric conditions, position changes vary from 1" to 30" of arc, and such displacements can hardly be observed with the naked eye. Only under abnormal atmospheric conditions are apparent position changes manifest. Their occurrence is most probably in the case of point sources, i.e., sources having no apparent diameter. Position changes of a planet like Venus or Jupiter do occur, but actual observations are limited to very unusual atmospheric conditions when the changes in direction of the planet's light rays are so large as to be of the same order of magnitude as the apparent diameter (0.5 to 1.0 minutes of arc).

In the case of an extended luminous source, a slow or rapid "pulsation" can be observed. This contraction and expansion of the image usually results in apparent changes of the image size. Occasionally, pulsation of the solar or lunar limb can be observed during setting or rising.

In general, the effects of scintillation are minimum when the luminous source is viewed near the zenith, and maximum when the source is viewed near the horizon. When terrestrial light sources are involved, the scintillation increases with distance and is highly dependent on the meteorological conditions.

The many detailed discussions of scintillation encountered in the literature are primarily concerned with the application of optical instruments to astronomy, optical communication, and optical ranging. In

this case, all light sources viewed through the atmosphere exhibit effects of scintillation irrespective of their position with respect to the zenith. When observations are made with the unaided eye,the above-mentioned effects of scintillation are manifested only when the observation concern objects close to the horizon (at low elevation or "low in the sky"). Under these conditions, the *most spectacular visual effects can be expected when the effects of scintillation (random refraction) are superposed on any visual image that arises from regular atmospheric refraction.*

The following section on aerosol particles has been contributed by Mr. Gordon D. Thayer of ESSA:

C. Light scattering by aerosol particles

An apparent optical image formed by light scattered out of a beam by a thin haze layer may be mistaken for a mirage. The theory of optical propagation in a scattering, attenuating atmosphere is well covered by Middleton (1952), an excellent reference containing much material on vision and the visibility of objects seen through the atmosphere.

The luminance or brightness, B, in e.g. lumens/m^2, of an extended object or optical source is invariant with distance except for losses due to scattering or absorption along the propagation path. Except under conditions of heavy fog, clouds, or smog, absorption is small compared to scattering, and may be neglected. If the scattering coefficient per unit length, σ , is constant, attenuation of a light source of intrinsic brightness B is given by

$$B = B_0 e^{-\sigma R},$$

where R is the distance of range travelled by the light from the source to the point of observation. The portion of brightness lost by scattering out of the path is given by

$$B_s = B_o \ (1 - e^{-\sigma R});$$

this loss represents light that is scattered in all directions by the molecules of air and aerosol particles present in the propagation path. Secondary scattering is neglected.

The quantity σR is often called the optical depth of an atmospheric layer, although it is a dimensionless quantity. Thus for thin layers where σR is small, the scattered light flux, F, in e.g. lumens, is

$$F_s \cong \sigma R F_o ,$$

where F is the light flux incident on the layer.

The intensity, I_s, or light flux per unit solid angle, of the light scattered from a small volume of air, v, is the product of the incident light lfux, F_o, the volume scattering function, $\beta'(\phi)$, and the average thickness of the volume. The scattering angle, ϕ, is defined in Fig. 16. The intensity of light scattered at an angle ϕ with respect to the incident beam is usually defined in terms of the incident illuminance, E, or flux per unit area in e.g., lumens/m^2 on an element of volume dv. This results in

$$dI(\phi) = E\beta'(\phi)\, dv, \qquad \text{hence, } I(\phi) = \int_V E\beta'(\phi)dv,$$

which, in the case of a small scattering volume where E and $\beta'(\phi)$ may be considered nearly constant over the entire volume, reduces to $I(\phi) \cong E_o\beta'(\phi)v$.

The units of $\beta'(\phi)$ are typically lumens scattered per unit solid angle per unit volume per lumen incident light per unit area; $I(\phi)$ then is expressed in candles, a unit of light intensity equal to one lumen per steradian. The volume scattering function is normalized by

$$2\pi \int_0^\pi \beta'(\phi) \sin \phi \sin \phi d\phi = \sigma;$$

hence for an isotropic scatterer, for which $\beta'(\phi)$ = const. = β'_o, $\beta' = \frac{\sigma}{4\pi}$. The volume scattering function relative to an isotropic scatterer is conveniently defined as

$$f(\phi) \equiv \frac{4\pi}{\sigma} \beta'(\phi)$$

The relative volume scattering function for very clear air has maxima at $\phi = 0°$ and 180°, $F(\phi) \cong 3.3$ and 1.7 respectively, and a minimum of $\phi = 90°$, $f(\phi) \cong 0.5$. Industrial haze, or smog, has a strong maximum at $\phi = 0°$, $F(\phi) \cong 8$, and a minimum at $\phi = 120°$ to 160°, $f(\phi) \cong 0.2$, with a weaker secondary maximum at $\phi = 180°$, $f(\phi) \cong 1.3$.

As an example of a scattering situation, consider a very clear atmosphere with a total vertical optical depth of 0.2; this is about twice the optical depth of a standard atmosphere of pure air (Middleton, (1952). The linear scattering coefficient, ϕ, for this atmosphere will be about $2 \times 10^{-5}m^{-1}$ near the ground. Assume that a haze layer one m in thickness and with an optical depty of 0.02 exists at 100 m above

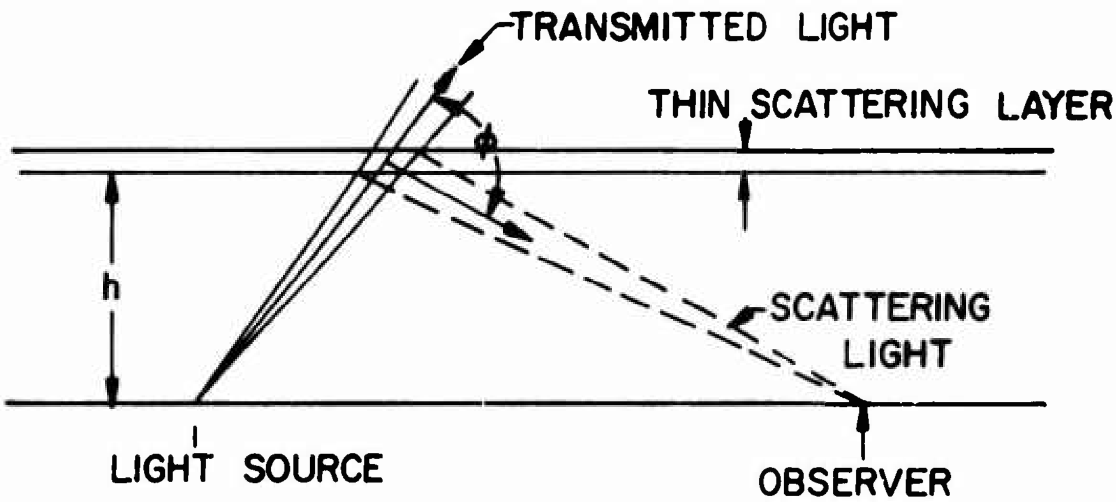


Fig. 16 GEOMETRY OF LIGHT SCATTERING

the ground; the total optical depth of the composite atmosphere will be 0.22. The value of σ appropriate to the haze layer is $2 \times 10^{-2} m^{-1}$, a factor of 10^3 greater than for the "clear" atmosphere above and below.

To an observer on the ground, the additional extinction of light caused by the presence of the haze layer, amounting to only 1.6% of the incident light from a source near the zenith, would not be perceptible except possibly very close to the horizon. However, light scattered out of an intense beam by the haze layer could be easily visible. Assume that a fairly powerful light source is aimed straight up from the ground; taking as typical values, e.g., for an automobile sealed beam unit, an intensity, I_o, of 3×10^4 candles (30,000 candlepower) and a beam width of 6°, the light flux incident on the layer at h = 100 m is

$$F_o = 236 \text{ lumens},$$

neglecting attenuation in the air below the layer. The beam solid angle, w_o, is 7.85×10^{-3} steradians. The incident illuminance, E_o, on the layer is

$$E_o = \frac{F_o}{A} = \frac{I_o}{h^2} = 3 \text{ lumens/m}^2$$

where the illuminated area, $A = w_o h^2$, is $78.5m^2$. The scattering volume, v, is $78.5m^3$ since the layer is one meter thick, and the intensity of the scattered light is

$$I(\phi) \doteq E_o \frac{\sigma}{4\pi} f(\phi)v$$
$$\doteq 3.75 \times 10^{-1} f(\phi) \quad \text{(candles)}.$$

If an observer is located 100 m from the light source, he will observe the scattered light at a distance of ~140 m and a scattering angle, ϕ, of 135°. The apparent source of the scattered light will appear to be elliptical, roughly 4° wide and 3° high, and will present an area normal to the observer, A_n, of 62.6 m^2. The value of $f(\phi)$ for a strongly scattering medium at ϕ = 135° is about 0.2; therefore the light scattered toward the observer is

$$I_s \doteq 7.5 \times 10^{-2} \text{ candles},$$

and the apparent brightness, B_s, of the scattering volume will be

$$B_s = \frac{I_s}{A_n} \doteq 1.2 \times 10^{-3} \text{ c/m}^2$$

A fairly dark, moonless night sky has a background brightness, B_b, of about 10^{-3} c/m^2; the scattered image would therefore have a total brightness of ~ 2.2×10^{-3} c/m^2 and a contrast against the night sky of $\varepsilon = B_s/B_b \doteq 1.2$. At this background brightness data given by Middleton (1952) show that the contrast required for 50% probability of detection for an object of 3^o-4^o diameter is about 5.7×10^{-2}; thus the image hypothesized in this example would have a brightness about 20 times greater than the minimum detectable, and would no doubt be easily visible as a pale, glowing, elliptical object.

In contrast, the air immediately above and below the haze layer with $\sigma = 2 \times 10^{-5}$ m^{-1} and $f(\phi) \doteq 1.1$ at $\phi = 135^o$ would yield a scattered brightness of only about 6.6×10^{-6} c/m^2 per meter thickness. The contrast against the night sky of the light scattered from the beam above or below the layer would therefore be on the order of 7×10^{-3}, which is not detectable with a background brightness of 10^{-3} c/m^2 according to Middleton (1952).

Increasing the background brightness to 10^{-2} c/m^2, corresponding to a bright, moonlit night, would decrease the contrast of the scattered image to 1.2×10^{-1}, which is about six times the minimum detectable contrast at that background brightness and the image would therefore still constitute a fairly obvious (object). Perception of light scattered from the rest of the beam under this increased background brightness, with $\varepsilon \doteq 6.6 \times 10^{-4}$, would be out of the question.

The level of background brightness for which the contrast of the image in this example would be reduced to the point where there is only a 50% probability of detection by an observer looking in the right direction is roughly 10^{-1} c/m^2; this value corresponds to the brightness of a clear sky about 1/2 hour after sunset.

Thus, scattering of light from sources of small beam width by localized haze layers in the lower atmosphere may cause the appearance of diffuse, glowing patches of light, moving with movement of the light source, that could easily be interpreted as a UFO by an observer unfamiliar with such phenomena. Data given by Middleton (1952) show that with common light sources and under average nighttime sky conditions, the main beam

of light could easily be imperceptible by scattered light, while at the same time the light scattered from a haze patch or layer would be easily visible to an observer; thus the source of the UFO-like image would not be apparent.

6. Evaluation of the State-of-the-Art Knowledge

During the last decade, active interest in optical mirage appears to have waned. The reasons for the apparent decline are believed to be two-fold. Firstly, on the basis of simple ray-tracing techniques, the mirage theories satisfactorily explain the various large-scale aspects of observations. Thus, no disturbing contradictions between theory and observation have been found. Secondly, although atmospheric refraction remains of great interest to astronomy, optical communication, and optical ranging, the phenomenon of the mirage has so far failed to demonstrate a major use.

At the present time, there is no *single* theoretical model that explains *all* the aspects, both macroscopic and microscopic, of the mirage phenomenon. The absence of such a model must stand as evidence that shortcomings remain in current knowledge. These shortcomings are most eloquently discussed by Sir. C. V. Raman (1959), who suggests and actually demonstrates that any approach to explain the phenomenon must be based on wave-optics rather than ray-optics. The theory of wave-optics as applied by Sir.C. V. Raman, suggests the presence of some intriguing aspects of the mirage that arise from the interference and focussing of wavefronts in selected regions of the refracting layer. Raman's experimental studies reveal that when a collimated pencil of light is incident obliquely on a heated plate in contact with air, the field of observation exhibits a dark region adjacent to the plate into which the incident radiation does not penetrate, followed by a layer in which there is an intense concentration of light and then again by a series of dark and bright bands of progressively diminishing intensity.

Further theoretical and experimental investigations are warranted in order to determine to what extent the brightening and brightness variations that arise from interference and focussing can add unusual effects to observations of phenomenon associated with abnormal refraction in the atmosphere.

7. Conclusions

When an unusual optical phenomenon is observed in the atmosphere, its positive identification as a mirage cannot be made without a physically meaningful description of what is seen and a complete set of meteorological and astronomical data. The required "hard" data are practically never available for the specific place and time of observation, so that the descriptive account remains the only basis for identification; in this case, successful identification depends on a process of education. Thus, the casual observer of an optical phenomenon can establish the likelihood that his observation is a mirage only by being aware of the basic characteristics of mirage and the physical principles that govern its appearance and behavior.

The conditions required for mirage formation and the principal characteristics of mirage images, as described in this report, are summarized below. The summary presents a set of standards by which to interpret the nature of an optical observation in terms of a specific natural atmospheric phenomenon.

A. Meteorological Conditions

Optical mirages arise from abnormal temperature gradients in the atmosphere. A temperature decrease with height (temperature lapse) exceeding 3.4°C per 100 m or a temperature increase with height (temperature inversion) is most commonly responsible for a mirage sighting.

Large temperature lapses are found in the first 10 meters above the ground during daytime. They occur when ground surfaces are heated by solar radiation, while during nighttime they can occur when cool air flows over a relatively warm surface such as a lake. When the temperature decreases with height more than 3.4°C per 100 m over a horizontal distance of 1 kilometer or more, an observer located within the area of temperature lapse can sight an inferior mirage near the ground (e.g., road mirage, "water" on the desert).

Layers of temperature inversion ranging in thickness from a few meters to several hundred meters may be located on the ground or at various levels above it. In areas where they are horizontally extensive, an observer can sight a superior mirage that usually appears far away (beyond 1 kilometer) and "low in the sky." The strength of the inversion determines the degree of image-elevation; the stronger the inversion, the higher the image appears above the horizon. Layers of maximum temperature inversion (30°C)

are usually found adjacent to the ground.

Calm, clear-weather conditions (no precipitation or high winds) and good horizontal visibility are favorable for mirage formation. Warm days or warm nights during the summer are most likely to produce the required temperature gradients.

B. Geometry of Illumination and Viewing

The geometry of illumination and viewing in the case of optical mirage is determined by the spatial variations of refraction index that occur in the cloud-free atmosphere, and by Snell's law of refraction, which relates these variations to changes in the direction of propagating wavefronts. The spatial variations in refractive index are associated with layers of temperature inversion or temperature lapse. Variations of 3×10^{-5}, corresponding to temperature changes of $30^{\circ}C$, are considered near maximum.

As a consequence of Snell's law and the small changes in the atmospheric refractive index, an optical mirage develops only when a temperature-inversion layer or a layer of large temperature lapse is illuminated at grazing incidence. The requirement of grazing incidence implies that the source of illumination must be either far away, i.e., near the horizon, or very close to or within the layer of temperature gradient. Therefore, both terrestrial and extraterrestrial sources can be involved. Because of the distance factor, the actual source of illumination may not be visible. Its location, however, must always be in the direction in which the mirage image is observed, i.e., observer, image and "mirrored" source are located in the same vertical plane.

Another consequence of Snell's law and the small spatial changes in refractive index is that noticeable refractive effects are not likely beyond an angular distance of approximately 14 degrees above the horizon and that a superior mirage image is not likely beyond an angular distance of 1 to 2 degrees above the horizon. Hence, mirages appear "low in the sky" and near the horizontal plane of view. An optical image seen near the zenith is not attributable to mirage.

Because of the restricted geometry between observer, mirage image, and source of illumination, the observed image can often be made to disappear abruptly by moving to higher or lower ground. Furthermore, when mirage

observations are made from a continuously moving position, the image can move also, or can move for a while and then abruptly disappear.

C. Shape and Color

A mirage can involve more than one image of a single object. Observations of up to four separate images, some inverted and some upright, are encountered in the literature. When multiple images occur they all lie in a single vertical plane or very close to it.

The apparent shape of a mirage can vary form clearly outlined images of an identifiable object such as a distant ship, landscape, or the sun or moon, to distorted images that defy any description in terms of known objects (e.g., Fata Morgana). Apparent stretching either in the vertical or in the horizontal plane is common.

During daytime, a mirage can appear silvery white ("water" on the ground), or dark when projected against a bright sky background, or it can reflect the general color of the land or seascape. Distinctly colored images ranging from red and yellow to green and blue are observed when unusual conditions of mirage occur near sunrise or sunset (e.g., Red and Green Flash) or, at night, during rising or setting of the moon or of a planet such as Venus.

In the presence of atmospheric turbulance and convection, the effects of scintillation become superimposed on the large-scale mirage image. When scintillation occurs, extended mirage images appear in constant motion by changing their shape and brightness. When the image is small and bright, as may be the case at night, large fluctuations in brightness and under unusual conditions in color can give an illusion of blinking, flashing, side to side oscillation, or motion toward and away from the observer. The effects associated with scintillation can dominate the visual appearance of any bright point-object in the area between the horizon and approximately 14 degrees above the horizon.

D. Present Uncertainties

The theory of ray optics adequately explains such observed large-scale aspects of the mirage as the number of images, image inversion, and apparent vertical stretching and shrinking. However, if the interference and focussing of wavefronts within the refracting layer are as fundamental

in mirage formation as purported by Sir C.V. Raman, the ray-tracing technique may have to be replaced by the theory of wave-optics.

Sir C. V. Raman's application of wave-optics to mirage suggests that under special conditions of illumination, the upper boundary of an atmospheric temperature inversion could exhibit a large concentration of radiant energy due to focussing of wavefronts. Also, interference of wavefronts could produce alternating layers of high and low brightness. Under what conditions and to what extent these brightness effects can be observed in the atmosphere is not known. Relevant observations have not been encountered in the literature, although some unusual observations of the green flash made under mirage conditions (O'Connel, 1958) could possibly have been caused by the enhancement of brightness in an inversion. The visual effects from focussing and interference of wavefronts must be considered as the least explored aspect of mirage.

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Chapter 5

Radar and the Observation of UFOs

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1. Introduction

This chapter covers studies of radar capabilities and limitations as they may be related to the apparent manifestation of unidentified flying objects. The studies were carried out by the Stanford Research Institute pursuant to a contract with University of Colorado (Order No. 73403) dated 23 June 1967, under sub-contract to the U.S. Air Force.

The preceding chapter of this report, entitled "Optical Mirage--A Survey of the Literature," by William Viezee, covers optical phenomena due to atmospheric light refraction.

As they became available other information and interim results of these studies were informally communicated to the University of Colorado study project in accordance with the referenced contract.

The purpose of this chapter is to provide a basic understanding of radar, the types of targets it can detect under various conditions, and a basis upon which specific radar reports may be studied. Studies of specific UFO incidents were performed by the Colorado project (see Section III, Chapter 5).

At first consideration, radar might appear to offer a positive, non-subjective method of observing UFOs. Radar seems to reduce data to ranges, altitudes, velocities, and such characteristics as radar reflectivity. On closer examination however, the radar method of looking at an object, although mechanically and electronically precise, is in many aspects substantially less comprehensive than the visual approach. In addition, the very techniques that provide the objective measurements are themselves susceptible to errors and anomalies that can be very misleading.

In this chapter we will consider how the radar principle applies to detection of targets that may be or appear to be UFOs, and attempt to establish the criteria by which such apparent manifestations must be judged in order to identify them. Since we make no assumptions regarding the nature of UFOs we limit ourselves to describing the principles by which radars detect targets and the ways in which targets appear when detected. In a word, we can only specify the nature of radar detection of targets in terms of physical principles, both in regard to real and actual targets and in regard to mechanisms which give rise to the apparent manifestation of targets. It is hoped that these specifications will assist in the review of specific instances as they arise. Even in cases where radar may identify target properties that cannot be explained within the accepted frame of understanding of our physical world, the authentic observation of a target having such properties will shed little or no light on its nature beyond the characteristics observed, and it will therefore remain unidentified.

2. Radar Systems

RADAR is an acronym for RAdio Detection And Ranging. It is a device for detecting certain types of targets and determining the range to the target. The majority of radars are also capable of

measuring the azimuth and elevation angles of targets.

Radars operate on three fundamental principles:

1) that radio energy is propagated at uniform and known velocity;
2) that radio energy is normally propagated in nearly straight lines, the direction of which can be controlled or recognized; and
3) that radio energy may be reradiated or "reflected" by matter intercepting the transmitted energy.

Basically radar consists of a transmitter that radiates pulses of electromagnetic energy through a steerable antenna, a receiver that detects and amplifies returned signals, and some type of display that presents information on received signals.

Radar systems can be separated into three general categories:

1) operational systems,
2) special usage systems and
3) experimental and research systems. These include fixed and portable ground-mounted systems, airborne, and shipborne systems.

Many types of radars are specifically designed to perform specialized functions. In general, radars provide either a tracking or a surveillance function. The surveillance radar may scan a limited sector or 360° and display the range and azimuth of all targets on a PPI (plan position indicator). Tracking radar locks onto the target of interest and continually tracks it, providing target coordinates including range, velocity, altitude, and other data. The data are usually in the form of punched or magnetic tape with digital display readout. Air traffic control, ship navigation, and weather radars fall into the surveillance category; whereas instrumentation, aircraft automatic landing, missile guidance, and fire control radars are usually tracking radars. Some of the newer generation of radar systems can provide both functions, but at this time these are very specialized systems of limited number and will not be discussed further.

In addition to the above general applications, each of the radar systems have special selective functions for various purposes. For example, some radar systems are designed so that they can track moving targets. Signals from stationary targets such as the ground, buildings, or even slow-moving objects are excluded from the display. This simplifies the display and makes it possible to track aircraft even though they are moving through an area from which strong ground clutter signals would otherwise mask the echo from the aircraft.

In addition to the many radar types, the radar operator has at his disposal many control functions enabling system parameters to be changed in order to improve the radar performance for increasing the detectability of particular types of targets, thereby minimizing interference, weather, and/or clutter effects. These radar system controls can modify any one or any combination of the following characteristics:

Transmitter output power
Pulse repetition rate
Sensitivity time control
Transmitted pulse width
AGC response time
IF receiver bandwidth
Transmitter operating frequency
Antenna scan rate
Polarization control of radiated and received energy
Skin or transponder beacon tracking
Receiver RF and IF gain
Display control functions
Numerous signal processing techniques for clutter suppression, weather effects, moving target indication, false alarm rate, and threshold controls.

The radar operator himself is an important part of radar systems. He must be well trained and familiar with all of the interacting factors affecting the operation and performance of his equipment. When an experienced operator is moved to a new location, an

important part of his retraining is learning pertinent factors related to expected anomalies due to local geographical and meteorological factors.

Two other groups of persons also affect the performance of the radar system. They are the radar design engineer and the radar maintenance personnel. The designer seeks to engineer a radar which achieves the performance desired, in addition to being a system which is both reliable and maintainable. Highly trained maintenance technicians routinely monitor the system insuring that it is functioning properly and is not being degraded by component system failures or being affected by other electronic systems that could cause electrical interference or system failure.

During the past 30 years, radar systems design has considerably improved. Radars manufactured today are more complex, versatile, sensitive, accurate, more powerful, and provide more data-processing aids to the operator at the display console. They are also more reliable and easier to maintain. In the process, they have become more sensitive to clutter, interference, propagation anomalies, and require better trained operating and maintenance personnel. Furthermore, with the increased data-processing aids to the operator, the more difficult becomes his target interpretation problem when the radar systems components begin gradually to degrade or when the propagation environment varies far from average conditions. The more sophisticated radar systems become, the more sensitive the system is to human, component, and environmental degradations.

3. Radar Fundamentals

Radar detection of targets is based on the fact that radio energy is reflected or reradiated back to the radar by various mechanisms. By transmitting pulses of energy and then 'listening' for a reflected return signal, the target is located. The period of time the radar

is transmitting one pulse is called the pulse length and is generally measured in microseconds (millionths of a second) or expressed in terms of the length from the front to the back edge of the pulse. (A one microsecond pulse is 984 ft. long, since radio waves, like light travel 186,000 statute mps.) The rate at which pulses are transmitted is called the pulse repetition rate. When pulses are transmitted at a high rate, the receiver listening time between pulses for return echoes is reduced as well as the corresponding distance to which the energy can travel and return. This means that the maximum unambiguous range is decreased with increasing pulse repetition rate. More distant targets may still return an echo to the radar after the next pulse has been transmitted but they are displayed by the radar as being from the most recent pulse. These so-called multiple trip echoes may be misleading, since they are displayed at much shorter ranges than their actual position.

Other important operating characteristics of a radar are its transmitted power and wavelength (or frequency). The strength of an echo from a target varies directly with the transmitted power. The wavelength is important in the detection of certain types of targets such as those composed of many small particles. When the particles are small relative to the wavelength, their detectability is greatly reduced. Thus drizzle is detectable by short wavelength (0.86 cm.) radars but is not generally detectable by longer (23 cm.) wavelength radars.

The outgoing radar energy is concentrated into a beam by the antenna. This radiation of the signal in a specific direction makes it possible to determine the coordinates of the target from knowledge of the azimuth and elevation angle of the antenna. The desired antenna pattern varies with the specific purpose for which the radar was designed. Search radars may have broad vertical beams and narrow horizontal beams so that the azimuth of targets can be accurately determined. Height finders on the other hand have broad horizontal beams so that the height of targets can be accurately determined. In either case the radiating and receiving surface of the antenna is usually a section of a paraboloid.

A circular beam may be described as a cone with maximum radiation along its axis and tapering off with angular distance from the center. The beam is described by the angle between the half power points (the angular distance at which the radiated power is half that along the axis of the beam). In the case of non-circular beams two angles are used, one to describe the horizontal beamwidth, a second to describe the vertical beamwidth. Later in this report the detection of targets by stray energy outside the main beam will be discussed.

The size of the beam for a given wavelength depends on the size of the parabola. For a given size parabola the longer the wavelength, the broader the beam.

When the radiated energy illuminates an object, the energy (except for a small amount that is absorbed as heat) is reradiated in all directions. The amount that is radiated directly back to the radar depends on the radar cross-section of the target. Differences between geometrical cross-section and radar cross-section are related to the material of which the object is composed, its shape, and also to the wavelength of the incident radiation. The radar cross-section of a target is customarily defined as the cross-sectional area of a perfectly conducting sphere that would return the same amount of energy to the radar as that returned by the actual target. The radar cross-section of complicated targets such as aircraft depends on the object's orientation with respect to the radar. A jet aircraft has a much smaller radar (and geometric) cross-section when viewed from the nose or the tail than when viewed broadside.

Equations relating the various parameters are given, in varying degrees of complexity, in textbooks on radar. In their simplest form the equations for average received power are:

For point targets (birds, insects, aircraft, balloons, etc.)

$$P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4} \qquad (1)$$

For plane targets (earth's surface at small depression angles)

$$\bar{P}_r = \frac{P_t G^2 \lambda^2 \Theta \; c T \sigma}{(4\pi)^3 \; R^3 \; 2} \tag{2}$$

For volume targets (precipitation)

$$\bar{P} = \frac{P_t G^2 \lambda^2 \quad \theta \psi \; c T \; \eta}{(4\pi)^3 \; R^2 \; 2} \tag{3}$$

Where:

P_r = average received power
P_t = transmitted power
G = Antenna gain
λ = wavelength
σ = radar cross-section
R = range of target
θ = horizontal beamwidth of antenna
c = velocity of radio waves
τ = length of transmitted pulse
ψ = vertical beamwidth of antenna
η = reflectivity per unit volume

These equations show that the intensity of echo signal varies according to whether the target is a point, a relatively small area, or a very large volume such as an extensive region of precipitation. The echo signal intensity of point targets varies inversely with the fourth power of the distance from the radar to the targets. The intensity of area targets varies with the cube of the distance, and that of large volume targets, with the square of the distance.

Figure 1 illustrates how the radar beamwidth and the cross-section area or volume of the target interact to give these different

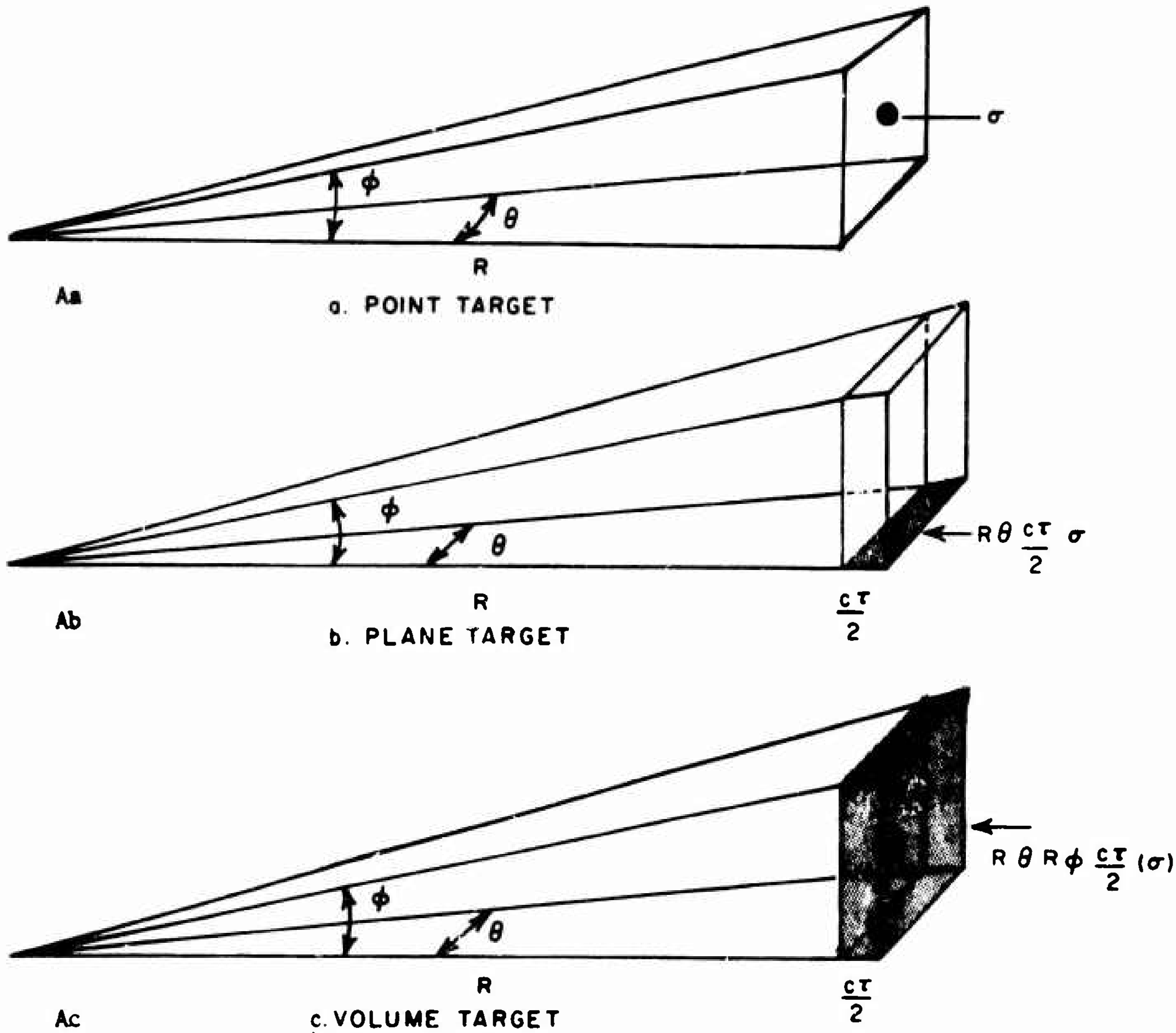


FIG. I RADAR CROSS SECTIONS OF VARIOUS TYPES OF TARGETS

variations with range of the returned signal. In Fig. Aa, the point target has a radar cross-section σ. In Fig. Ab there may be a number of targets with radar cross-section σ over an area with dimensions of half the pulse length and the beam width at range R. Replacing σ in equation (1) with this new expression for radar cross-section cancels one R in the denominator giving the R^3 relationship. When the target is many σ's spread over a volume with dimensions determined by range, horizontal and vertical beamwidth, and half the pulse length (Fig. Ac) R appears in the numerator twice, thus cancelling an R^2 in the denominator of equation (1).

Because of differences in variation with distance of the return signal from various types of targets it is apparent that with combinations of targets the point targets might not be detectable. For example, an aircraft cannot be detected when it is flying through precipitation or in an area of ground targets unless special techniques are used to reduce the echo from precipitation or ground clutter.

Information on signals returned to the radar by a target may be presented to an operator in a number of ways; by lights or sounds that indicate there is a target at a selected location; by numbers that give the azimuth, elevation angle, and range of a selected target; or in 'picture' form showing all targets within range that are detected as the antenna rotates. The latter form of presentation is called a Plan Position Indicator (PPI). Plate 65 shows a photograph of a PPI. This photograph is a time exposure equal to the time for one antenna revolution. The center of the photograph is the location of the radar station. Concentric circles around the center indicate distance from the station. In this case the range circles are at 10 mi. intervals, so the total displayed range is 150 mi. North is at the top of the photograph and lines radiating from the center are at 10° intervals. A PPI display such as this corresponds very closely to a map. Often overlays with locations of cities, state boundaries, or other pertinent coordinates are superimposed over the PPI to aid

in locating echoes. The plate shows a number of white dots or areas at various locations. These may be echoes from a variety of different targets, or they may be the result of interference or system malfunction.

The radar operator must keep watch of this entire area (70,650 sq. mi. in this example) and try to determine the nature of the targets. If he is a meteorologist he watches for and tracks weather phenomena and ignores echoes which are obviously not weather-related. If he is an air traffic controller he concentrates on those echoes that are from aircraft for which he is responsible. Many unexplained radar echoes are not studied or reported for several reasons. One of the reasons might be that the operators in general only track targets that they can positively identify and control. Since a radar operator can only handle a limited number (6 to 8) of targets simultaneously, he might not take serious note of any strange targets unless they appear to interfere with the normal traffic he is vectoring. Even when the unexplained extraordinary targets are displayed, he has little time available to track and analyze these targets. His time is fully occupied observing the known targets for which he is responsible. In addition, the operator is familiar with locally recurring strange phenomena due to propagation conditions and suspects the meteorological environment as being the cause. In general, the operator seldom has a way in which to record the displayed data for later study and analysis by specialists.

In addition to the tracking of various targets he must also be aware of the possibility of malfunction of the radar.

4. System Reliability

Two types of failures occur in a radar system: those that are catastrophic and those that cause a gradual degradation. In spite of good maintenance procedures, there will be system component failures that occur due to external events such as ice or wind loading, rain

on the cabling and connectors, bugs and birds in the feed structure. The operator is not always immediately aware of such failures. He is usually located in a soundproofed and windowless room remote from the transmitter, antenna, and receiving hardware. The operator has available to him only the console display and readout equipment. Catastrophic systems failure is usually self-evident to the operator. When the transmitter power tube fails, or the antenna drive unit fails, the operator is aware of this immediately on his PPI display. But when the gain in a receiving tube decreases, or the system noise slowly increases due to a component degradation, or the AFC in the transmitter section begins to go out of tolerance over a period of days causing increased frequency modulation or "pulse jitter" in the transmitted pulse, time may elapse before the operator becomes aware of the slowly deteriorating performance. Reduced sensitivity or the increased reception of extraneous targets from ground clutter or nearby reflecting structure is often evidence that the radar system is deteriorating.

It can be considered that a major system component of a typical radar might be subject to catastropic failure every 250 to 2,000 hours of operation (5 to 36 average failure-free days) and that graceful degradations of components occur continually. Possible failure thus becomes one of the first causes to be considered in analyzing unusual radar sightings. The next factor will be possible unusual propagation effects to which the radar is subject. Analysis of extraordinary sightings is further handicapped by the fact that the displayed data of the sighting usually are not recorded and that any explanations must frequently be based upon interpretations by the operators present at the time of the sighting. The point is that the operator, the radar, and the propagation medium are all fallible parts of the system.

5. Relationships between Echoes and Targets

There are five possible relationships between radar echoes and targets.

These are:

a) no echo - no target;

b) no echo - when a visual object appears to be in a position to be detected;

c) echo - unrelated to a target;

d) echo - from a target in a position other than that indicated;

e) echo - from a target at the indicated location.

The first and last possibilities are indicative of normal function. Possibility b) becomes of importance where there is an object that is seen visually. Then, from knowledge of the types of targets that are detectable by the radar, some knowledge of the characteristics of the visual object could be obtained.

The situations c) where there is an apparent echo but no target are those when the manifestation on the PPI is due to a signal that is not a reradiated portion of the transmitted pulse but is due to another source. These are discussed in a subsequent section of this chapter.

Situations where the echo is from a target *not* at the indicated location d) may arise due to one or a combination of the following reasons. First, abnormal bending of the radar beam may take place due to atmospheric conditions. Second, a detectable target may be present beyond the designed range of the radar and be presented on the display as if it were within the designed range, for example, multiple-trip echos from artificial satellites with large radar cross-sections. Third, stray energy from the antenna may be reflected from an obstacle to a target in a direction quite different from that in which the antenna is pointed. Since the echo is presented on the display along the azimuth toward which the antenna is pointed the displayed position will be incorrect. Finally, targets could be detected

by radiation in side lobes and would be presented on the display as if they were detected by the main beam.

Possibility e) listed above encompasses the broad range of situations where there is a target at the location indicated on the display system. Of primary concern in this case is the identification of the target.

The possible relationships listed above show that radarscope interpretation is not simple. To attempt to identify targets, the operator must know the characteristics of his radar; whether it is operating properly; and the type of targets it is capable of detecting. He must be very aware of the conditions or events by which echoes will be presented on the radar in a position that is different from the true target location (or in the case of interference by no target). Finally, the operator must acquire collateral information (weather data, transponder, voice communication, visual observations or handover information from another radar before he can be absolutely sure he has identified an unusual echo.

6. Signal Sources

Sources of electromagnetic radiation that may cause real or apparent echoes on the radar display include both radiators and reradiators. Some sources, such as ionospheric electron backscatter, the sun, and the planets, are not considered, since they can be detected only by the most sensitive of research radars. As a radiator the sun does emit enough energy at microwave wavelengths to produce a noise signal. This signal has been used for research purposes (Walker 1962) to check the alignment of the radar antenna. Radio sextants have been built which track the sun at cm. wavelengths by Collins Radio Co. Since this signal is quite weak it is unlikely it would be noticed during routine operation of a search radar.

Reradiators include objects or atmospheric conditions that intercept and reradiate energy transmitted by the radar. Objects range in size from the side of a mountain to insects. Atmospheric conditions include ionized regions such as those caused by lightning discharges

and inhomogeneities in refractive index caused by sharp discontinuities in temperature and moisture.

Table 1 lists some radiators and reradiators. This list is incomplete since continuing development of new types of radars or improvements due to evolutionary growth of existing radars results in new types of targets becoming detectable.

Table 1

Radiators and Reradiators

1. Precipitation
2. Aircraft
3. Birds and Insects
4. Satellites, Space Debris, and Missiles
5. Ionization Phenomena or Plasmas
6. Balloons
7. Chaff, "Window," and "Rope"
8. Smoke
9. Distant Ground Return and "Angels"
10. Radio Frequency Interference

The signal sources listed have relatively unique sets of characteristics although in many cases there is some overlap. For example, a fast flying bird with a tailwind could have ground speeds comparable to a light aircraft with a headwind. At comparable range, however, the signal intensity would be quite different unless the bird were in the main beam and the aircraft in a side lobe. This section will discuss the typical characteristics and behavior of the return signals and the auxiliary information needed to confirm or reject them as the sources of a given echo will be mentioned. For example, as mentioned above, knowledge of wind speed is necessary to determine the air speed of a target.

In the discussion of detectability of the various signal sources some specific frequency bands may be mentioned. Figure 2 illustrates the relationships between wavelengths and frequency in the various bands and shows specific radar bands within the frequency and wavelength spectrum.

Precipitation

In the 1940's when radar technology advanced to the point where wavelengths less than half a meter began to be feasible, precipitation became a radar-detectable target. Ligda (1961) states that the first radar storm observation was made on 20 February 1941 in England with a 10 cm. (S band) wavelength radar. Since that time, radar has been widely used for meteorological purposes and special meteorological radars have been designed and constructed specifically for precipitation studies (Williams, 1952; Rockney, 1958). Many radars designed for purposes other than weather detection were found to be very adequate as precipitation detectors. Ligda (1957) studied the distribution of precipitation over large areas of the United States using PPI photographs from Air Defense Command (ADC) Radars during the period 1954 to 1958 and during 1959 studied the distribution of maritime precipitation shown by PPI photographs from radars aboard ships of Radar Picket Squadron I stationed off the west coast of the United States. Later programs concurrent with several of the meteorological satellites (Nagle, 1963; Blackmer, 1968) have also utilized data from ADC and Navy radars. Thus radars designed for other specific missions are often capable of detecting precipitation and an understanding of the characteristic behavior and appearance of precipitation is essential if the radar operator is to interpret properly the targets his radar detects.

Detailed studies have been made of characteristics of radar returns from precipitation. In a review of the microwave properties of precipitation particles Gunn and East (1954) discuss variations in return signal with wavelength and differences between the return signal from liquid and frozen water particles. Precipitation consists of a large volume of particles that generally fill the beam at moderate ranges. The

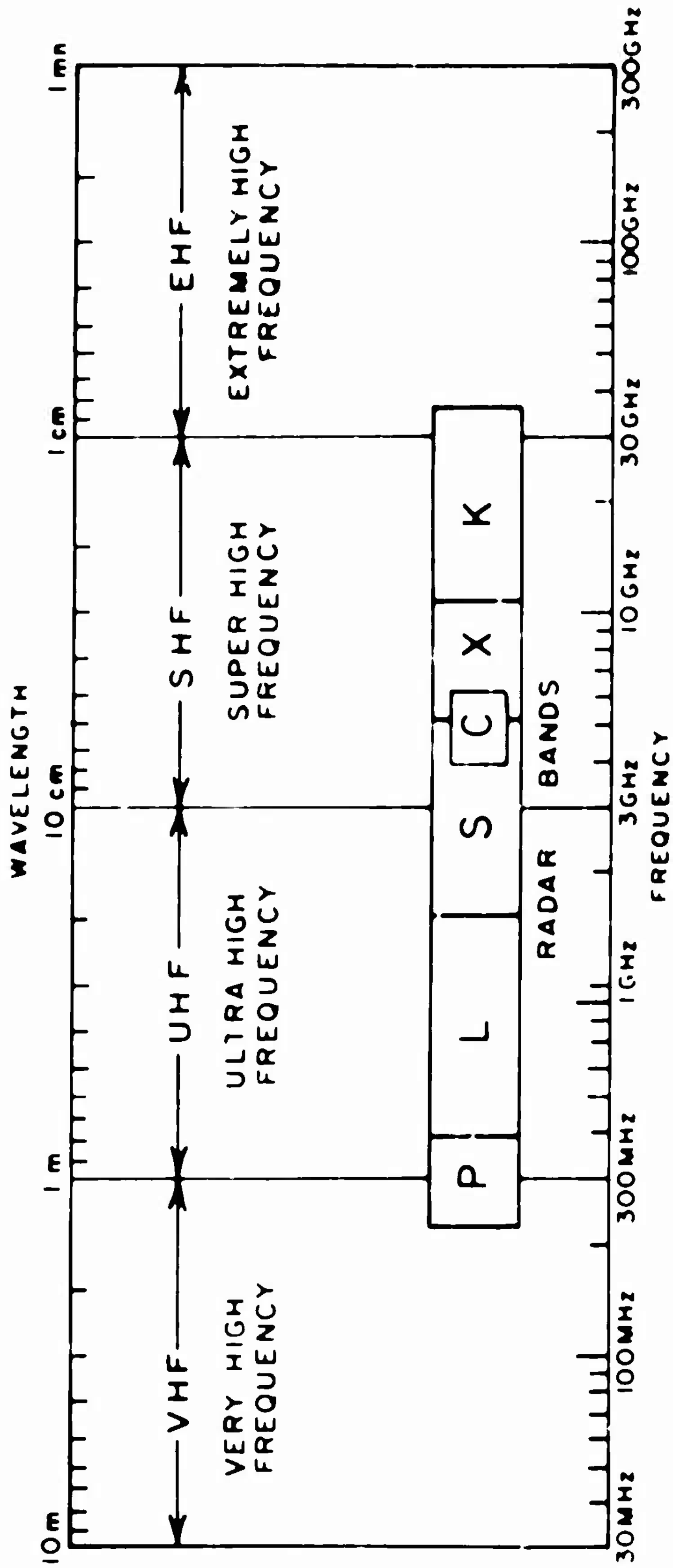


FIG [illegible] COMMON DESIGNATION OF FREQUENCY BANDS

received power at any instant is the resultant of the signals from the large number of individual particles. The particles are constantly changing position relative to each other (and to the radar site). As a result the signals from the individual particles sometimes add to give a strong return, sometimes subtract to give a weaker signal. This fluctuation in echo from precipitation is readily apparent on scopes that permit examination of the return from individual transmitted pulses. The fluctuation of the return signal is not, however, apparent to a radar operator monitoring the PPI of a search radar. This is because the persistence of the cathode ray tube used for PPI displays averages or integrates a number of pulses. Of importance to a radar operator concerned with interpreting the PPI is the variation of signal intensity with wavelength, with pulse length and with precipitation type. Particles that are large compared to the wavelength are more readily detectable than those that are small compared to the wavelength. Light drizzle may be barely detectable at short ranges while severe thunderstorms with large raindrops are detectable at ranges of 300 - 400 mi. When there is large hail falling from a severe thunderstorm the return signal may be quite strong.

Radar-detected precipitation may be in a variety of forms from very widespread continuous areas of stratiform precipitation of sufficient vertical extent to nearly cover the PPI of a long-range (150 n.mi.) search radar to only one or two isolated small sharp edged convective showers. The former is likely to persist for many hours, the latter for only a fraction of an hour. Between these two extremes there are many complex mixtures of convective and stratiform precipitation areas of various sizes. One of the distinguishing features of precipitation echoes is their vertical extent and maximum altitude. Usually precipitation echoes extend from the surface to altitudes up to 60,000 ft., although a more common altitude of tops is 20,000 - 40,000 ft. Further, isolated small volumes of precipitation seldom remain suspended in the atmosphere. The initial echoes from showers and thunderstorms may appear as small targets at moderate altitudes but subsequently grow

rapidly. For example, Hilst and MacDowell (1950) examined the initial echoes from a thunderstorm. Horizontal measurements were made with a 10 cm. radar and the vertical measurements were made with a 3 cm. radar. Their first measurement showed a small horizontal area and a vertical extent from 11,000 - 18,000 ft. Presumably measurements a short time earlier would have shown smaller dimensions. Subsequently there was rapid growth to an area of 200 sq. mi. and a vertical extent from the surface to about 30,000 ft. The importance of this large vertical extent is that such an echo on the PPI of a search radar with a narrow beam can be present at a variety of ranges; that is, the beam will not be below the target at short ranges or above it at long ranges as would be the case with targets of limited vertical extent.

Since precipitation is less detectable at longer wavelengths and showers may have a quite short lifetime, it is possible that on rare occasions precipitation targets could confuse the radar operator. Consider for example a search radar operating at wavelengths of greater than 20 cm. in an environment where short-lived showers were occurring. A study by Blackmer (1955) using photographs from a 10 cm. radar showed a peak in echo lifetimes of 25 - 30 min. while the mean lifetime was 42 min. Also using data from an S band radar, Battan (1953) found a mean echo duration of 23 min. with the greatest number having lifetimes of 20.0 - 24.9 min. At longer wavelengths with short lifetimes, it is not impossible that an intense shower would be detectable only in the brief period during which it was producing hail, because a long-wavelength radar might not detect small precipitation particles but could detect hail. Water-coated hail acts as a large water sphere and thus gives very strong return signals even at long wavelengths. Geotis (1963) found that hail echoes are very intense subcells on the order of 100 M. in size. When a number of short-lived showers or long-lived showers that were detectable only when hail is falling, are within range of a long-wavelength radar, the PPI display could show over a period of time, a brief echo at one location, then an echo at a new location for a

short period, etc. This might be interpreted as a single echo that was nearly stationary for a short period then moving abruptly to a new position.

One of the characteristics of precipitation echoes is that their motion is very close to that of the wind direction and speed. This wind velocity may not be the same as that observed at the radar site if the distance to the precipitation is great. Occasions have also been noted when precipitation echoes within a relatively small area have shown differences in motion due to being moved by different wind directions at various levels.

In general, however, precipitation is a relatively well behaved radar target and except for rare instances its extensiveness and orderly movement readily identifies it to the radar operator monitoring a PPI display.

Aircraft

The term aircraft includes a wide variety of vehicles from unpowered sailplanes to the most advanced military jets with speeds several times that of sound. A target such as an aircraft has a very complex shape that is many times the wavelength of the incident radar energy. As the energy scattered from different parts of the aircraft adds or subtracts from other parts, the signal returned to the radar fluctuates. Fluctuations in the echo can also result from changes in the angle at which the aircraft is viewed. That is, when an aircraft is viewed broadside, its radar (and visual) cross-section is much larger than when viewed from the nose or tail. Skolnik (1962) reports a 15 dB change in echo intensity with an aspect change of only 1/3 of a degree. High frequency fluctuations due to jet turbines (Edrington, 1965) and propellors (Skolnik, 1962) have also been reported. These fluctuations are on the order of 1000 cycles per second and would not be apparent on a PPI.

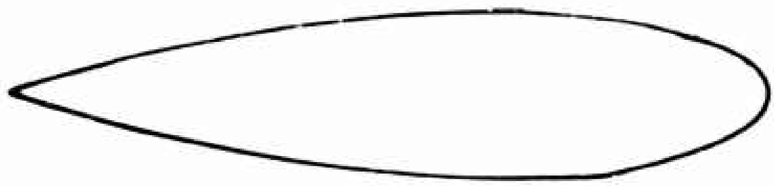
Although aircraft echoes fluctuate due to aspect and propulsion modulations, there is a general correlation between size of aircraft and the amount of signal returned to the radar. An indication of the

relative detectability of several aircraft as given by the Air Force (1954) is F-86 = 0.46, B-45 = 0.75, B-17 = 1.0, B-29 = 1.2. The numbers mean that, if on a given radar a B-17 was just detectable at 100 mi., an F-86 would be just detectable at 46 mi.

The radar cross-sections of components of a large jet aircraft was measured with a 71 cm. radar (Skolnik 1962) and maximum values in excess of 100 m^2 were found. The fuselage of the large jet when viewed from the front or rear had a cross-section of about one-half square meter. Smaller aircraft would have much smaller radar cross-section of about one-half square meter. Smaller aircraft would have much smaller radar cross-sections and light aircraft or sailplanes of fiberglass or wooden construction could have extremely small radar cross-sections.

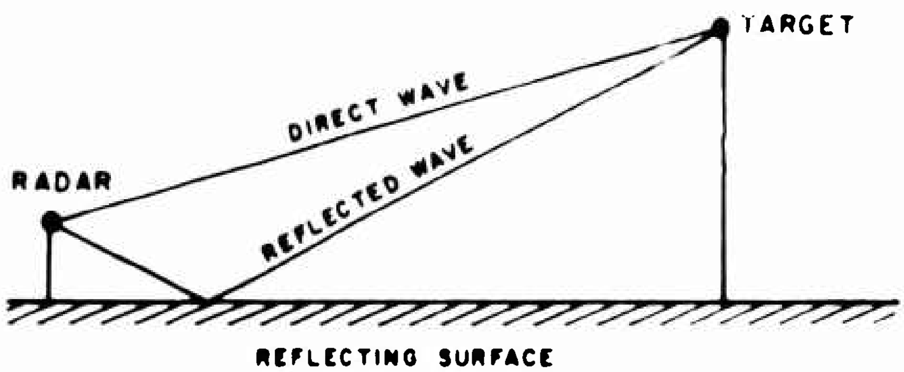
Another type of fluctuation in echo signal from aircraft and similar point targets is due to the nature of radio wave propagation. When a radar wave is propagated over a plane reflecting surface there will be reflections from that surface to a target in addition to the direct path from the radar to the target. Figure 3 illustrates the geometry of beam distortion due to such a plane reflecting surface. In Fig.3a an idealized beam pattern in free space is shown. When a reflecting surface such as the ground or sea surface is introduced a portion of the beam will be reflected from the surface as in Fig.3b. A target will thus be illuminated both by a direct wave and a reflected wave. The echo signal from the target back to the radar travels over the two paths so that the echo is composed of two components. The resulting echo intensity will depend on the extent to which the two components are in phase. Areas along which the two components are in phase resulting in a stronger signal lie along lines of angular elevation of $\frac{2\lambda}{4h_a}, \frac{3\lambda}{4h_a}, \frac{5\lambda}{4h_a}, \ldots$ (λ = wavelength and h_a = antenna height). The two components are out of phase and nearly cancel each other between the maxima. The resulting beam pattern thus consists of a series of lobes as presented schematically in Fig. 3c. As an aircraft flies along it will progress through the regions of maxima and minima, and the signal will fluctuate from near zero in the minima to a value near twice the fre -space intensity in the maxima.

Ea



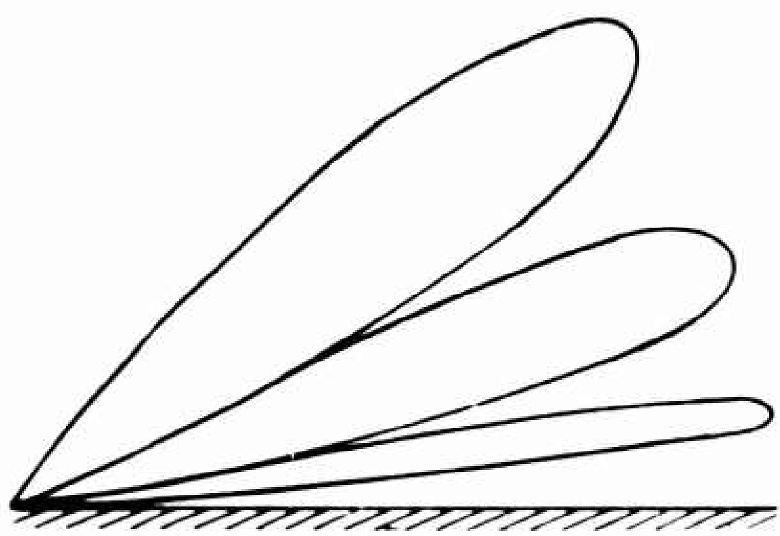
a. FREE SPACE BEAM PATTERN

Eb



b. REFLECTION BY PLANE SURFACE

Ec



c. BEAM PATTERN WITH PLANE REFLECTING SURFACE

FIG. 3 DISTORTION OF RADAR BEAM DUE TO PLANE REFLECTING GROUND SURFACE

The foregoing assumes a plane, perfectly reflecting surface. Since the surface in the vicinity of a radar station is generally not a plane and its reflecting qualities vary the situation is much more complex than the idealized case.

The effect of these fade areas is to cause aircraft targets to sometimes disappear and then (if the target has not reached a range such that the return signal is no longer detectable) to reappear. With a number of aircraft flying about it is not inconceivable that the fadings and reappearances of the several aircraft would be difficult to keep track of and could be misinterpreted as a smaller number of targets that were moving quite erratically.

Considering the whole spectrum of vehicles that travel in the atmosphere, there may be speeds as low as zero (hovering helicopter) or speeds exceeding Mach 3.0. Correspondingly, altitudes vary from the surface to 50,000 - 60,000 ft. (in some cases above 100,000 ft.) Different types of aircraft, however, are limited in their range of speeds and altitudes. A hovering helicopter cannot suddenly accelerate to three times the speed of sound. Neither can a supersonic jet hover at 60,000 ft. A characteristic of an aircraft echo on a PPI is therefore its relative uniformity of movement. To monitor this movement allowance must be made for fades. The direction of movement also will be quite independent of wind direction at flight level.

Birds and insects

Possibly the earliest observation of a radar echo from a bird was made by R. M. Page (1939) of the Naval Research Laboratory in February, 1939. It was made with an experimental 200 MHz. radar (the XAF) on the *U.S.S. New York* near Puerto Rico. Bird echoes, as reported by Lack and Varley (1945), were observed on a 10 cm. coast-watching radar set near Dover during 1941. Visual checks confirmed both of these early detections by radar as being returns of individual birds. Numerous bird observations by radar have been made since,

especially of bird migrations as is evidenced in a bibliography compiled by Myres (1964) listing 89 papers, and a text written by Eastwood (1967). Radar cross-sections (σ) have been measured of birds in a fixed position suspended in a non-reflecting sling and of birds in flight. The values obtained, shown in Tables 2 and 3, vary with species, aspect, and radar wavelength.

Because of the inverse-fourth-power variation with range, a bird at short range in the main beam can give a radar echo comparable in intensity to that from an aircraft in the main beam at a long range. For example, if a pigeon with a broadside radar cross-section of 100 cm^2 were flying within the radar main beam at a range of 10 mi., it would produce as strong a signal to the radar as a jet aircraft with a σ value of 10^6 cm^2 (100 m^2) flying within the radar main beam at a range of 100 mi. However, if the aircraft were flying in a side-lobe 40 dB less powerful than the main beam in which the bird is flying both would produce equal intensity signals at the same range. If the side lobe were 30 dB down, a bird in the main beam at 10 mi. would look like an aircraft at 17.8 mi., and if the side lobe were 20 dB down, the bird at 10 mi. would look like an aircraft at 31.6 mi.

Theoretically the maximum detectable range as dictated by the amount of radar signal returned from birds can be calculated. However, verification is not easy due to the difficulty of spotting a bird and establishing that it belongs to a particular blip on a radar scope. This is particularly difficult in the presence of sea clutter as experienced during an experiment conducted by Allen and Ligda (1966) at Stanford Research Institute. During an experiment conducted by Konrad (1968), individual birds were released from an aircraft flying over water at 5,500 - 6,000 ft. from 8 - 10 n.mi. from the radars. After separation of the aircraft from the bird in the radar scope, each individual bird was automatically tracked for periods up to five minutes, so that the target observed was positively identified as a bird. Flocks of birds have been detected to ranges of at least 51 n.mi. as reported by Eastwood and Rider (1965).

Table 2

SUMMARY OF BIRD RADAR CROSS-SECTION DATA

(from Konrad, Hicks, and Dobson 1968)

Radar Band	Points at point/sec)	Mean radar Cross-section (cm^2)	Median radar cross-section (cm^2)	Root-mean-square fluctuations in cross section (cm2)	Mean-to-median ratio, p
		Grackle			
X	230	16	6.5	24	2.4
S	230	27	13	31	2.2
UHF-VV*	230	0.73	0.58	0.6	1.3
UHF-VH†	230	0.37	0.15	0.7	
		Grackle			
X	116	15	7.2	21	2.1
S	116	23	11	32	2.2
UHF-VV	116	0.41	0.32	0.5	1.3
UHF-VH	116	0.03	0.015	0.04	
		Sparrow			
X	129	1.9	1.0	2	1.9
S	129	15	11	11	1.4
UHF-VV	129	0.025	0.02	0.02	1.3
UHF-VH	129				
		Sparrow			
X	233	1.3	0.60	2	2.2
S	223	12	11	5	1.1
UHF-VV	233	0.020	0.02	0.01	1.1
UHF-VH	233				
		Pigeon			
X	160	15	6.4	28	2.3
S	160	80	32	140	2.5
UHF-VV	160	11	8.0	7.0	1.3
UHF-VH	160	1.2	0.7	1.4	

*VV, Transmit vertical polarization and receive vertical polarization.
†VH, Transmit vertical polarization and receive cross-polarized or or horizontal component.

Table 3

VARIATION OF RADAR CROSS-SECTION WITH ASPECT

(from Konrad, Hicks, and Dobson 1968)

Radar Band	Aspect*	Radar cross-section σ (cm^2)
	Starling (Sturnus vulgaris)	
X	Head	1.8
X	Broadside	25.0
X	Tail	1.3
	Pigeon (Columba livia)	
X	Head	1.1
X	Broadside	100
X	Tail	1.0
	House sparrow (Passer domesticus)	
X	Head	0.25
X	Broadside	7.0
X	Tail	0.18
	Rook (Corvus frugilegus)	
X	Broadside	250
	Turkey buzzard	
X	Unknown	25 to 250
	Duck and chicken	
UHF+	Head	600
UHF+	Tail	24

*For the cross-section measurements of the starling, pigeon, sparrow, and rook, the birds were suspended from a tower with their wings folded; the radar elevation angle was 18°. Measurements of the turkey buzzard were made when the bird was in flight; measurements of the duck and chicken were made when the birds were standing or squatting. +400 megacycles.

Very few birds fly over 13,000 ft.; most fly below 5,000 ft. In a survey conducted by Farrari (1966) of USAF reports of bird-aircraft collisions during 1965, 27% of all collisions were under 100 ft. 28% between 100 - 2,000 ft., 21% between 2,000 - 3,000 ft. and the 24% above 3,000 ft. If it can be assumed that the probability of a bird-aircraft collision is equally likely at all altitudes (which may not be fully valid due to climb and descent) this should be somewhat of a representative figure of the height of flight for birds. There was one reported bird-aircraft strike at 17,000 ft. and a few sightings above 20,000 ft., however the number of birds flying at these altitudes appears to be extremely small.

Eastwood and Rider (1965) reported a rather complete analysis of the height of flight of various birds observed by radar at the Marconi Research Laboratory in England. Their findings agreed very closely with the above; about 90% of all birds were below 5,000 ft. Birds fly higher at night and during the spring and fall migration periods. A plot of the average altitude distribution over the year is shown in Fig. 4. All of these figures are probably applicable as height above the general terrain; i.e., at 5,000 ft. above mean sea level, 90% of the birds would fly at altitudes below 10,000 ft.m.s.l. The amount of cloud cover also affects the height at which birds fly. Diagrams included by Eastwood and Rider (1965) clearly indicate a marked tendency for higher mean altitudes to be flown in the presence of complete cloud cover.

Target airspeed is another means for identifying a bird. It can be obtained vectorially from a knowledge of the wind velocity and the radar-measured target velocity. Houghton (1964) determined the airspeed of a limited sampling of the birds by visually identifying each through a telescope aimed by tracking radar Fig. 5. In all cases the wind speeds were less than 5 knots. Target air speed cannot invariably distinguish between a helicopter, a slow moving aircraft and a bird flying in a high wind without precise knowledge of the wind at the bird altitude.

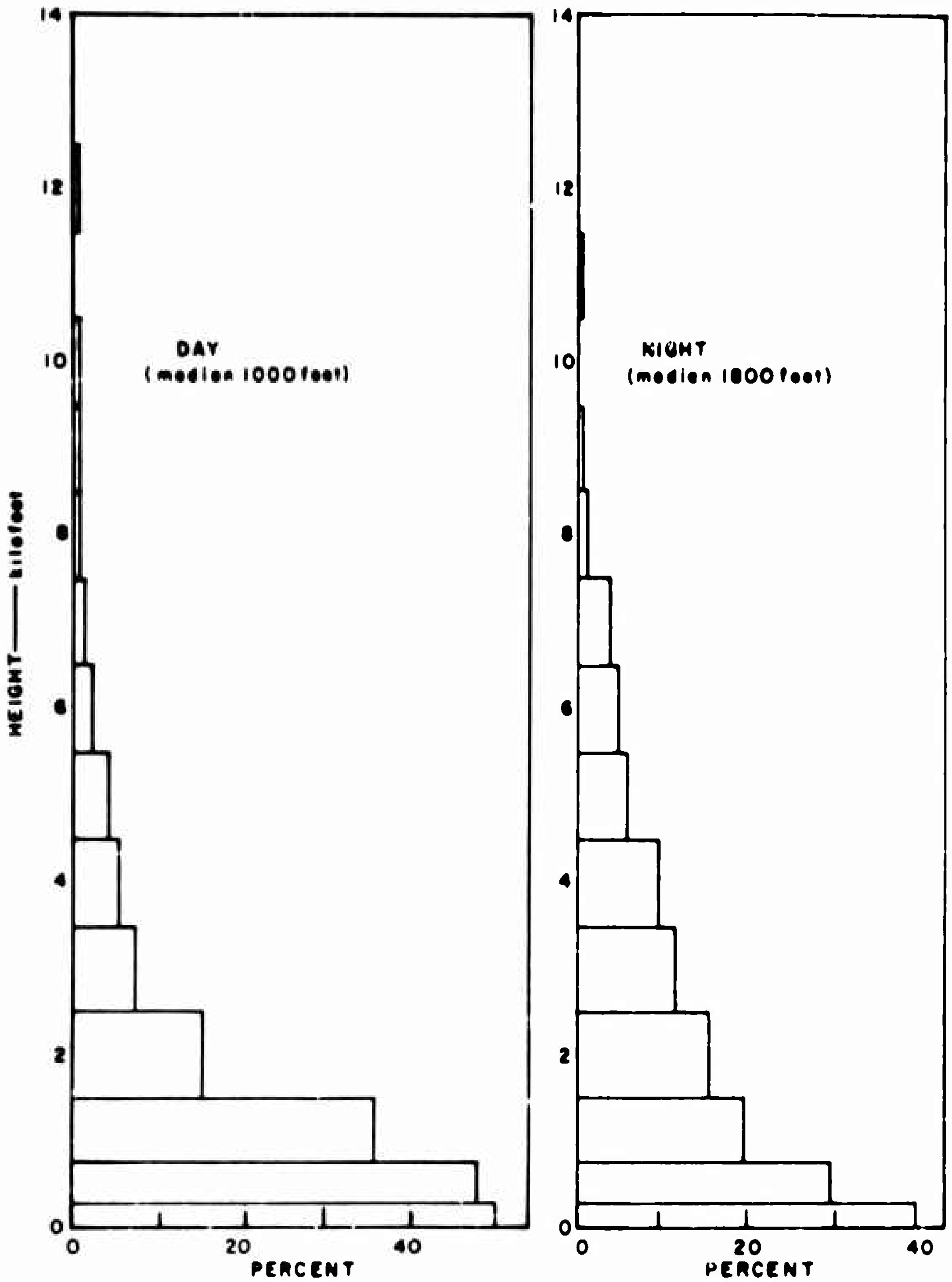


FIG. 4 AVERAGE ALTITUDE DISTRIBUTION OF BIRDS OVER THE YEAR (from EASTWOOD and RIDER 1965)

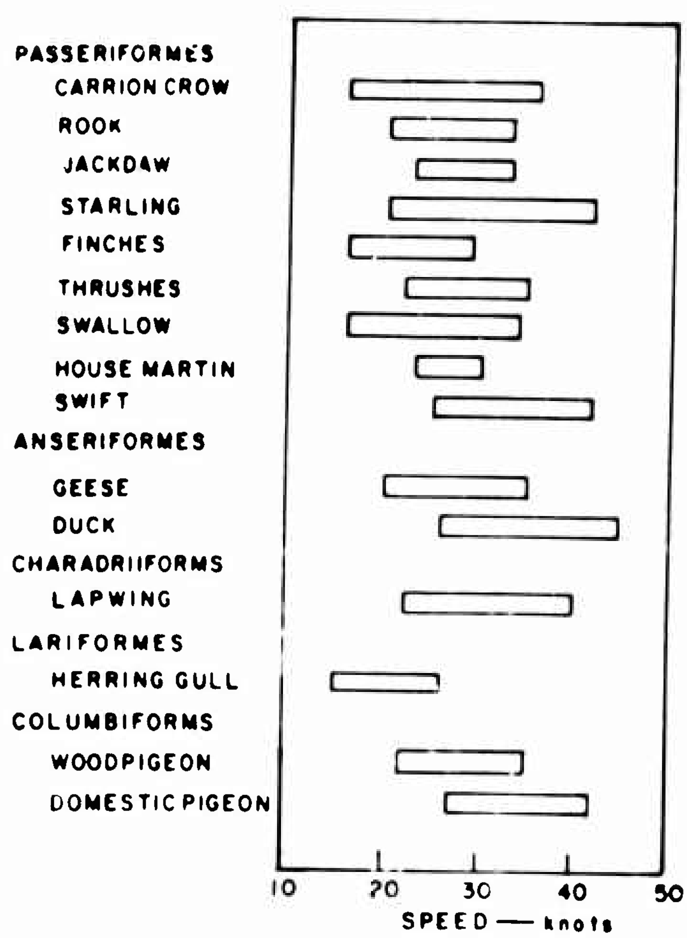


FIG. 5 BIRD AIRSPEED CHART
(from HOUGHTON 1964)

Flocks of birds sometimes produce rings on a radar scope which expand from a number of fixed points. These have been called "ring angels" and were first attributed to birds by Ligda (1958). Visual confirming observations were lacking at that time. Later, Eastwood, Isted and Rider (1962) verified that radar ring angels were definitely caused by the dispersal of starlings (Sturnus vulgaris) from their roosts at sunrise. After several radar scope observations were studied, it became possible to pinpoint the centers of the rings and the approximate locations of the roosts. A number of observers equipped with radio telephones were stationed at each location and signaled the precise moment of emergence of the successive flocks of starlings from the roost under observations. These data were correlated with the radar scope presentations to confirm definitely the generation of ring angels by birds. The mean air speed of starlings leaving the roost was measured as 37 knots.

Under some conditions, slow-moving ring echoes may be produced by the rise of a temperature inversion layer in the early morning hours after sunrise. Sea-breeze fronts have occasionally been seen on radar as a line, and at other times as a boundary between scattered and concentrated signal returns as shown by Eastwood (1967). How much of the line produced is due to the meteorological effects and how much by birds and insects is still a matter for speculation. However, Eastwood (1967) cites reports by glider pilots sharing up-currents with birds taking advantages of the lift provided. This and some limited study of the characteristics of the radar scope signals, produce some indication as to the validity of the bird theory.

Some studies have been made on target signal fluctuation and other signature analysis techiques in connection with birds (Eastwood, 1967) and even with insects (Glover, 1966). Some of the signal characteristics have been attributed to aspect of the target and others to wing motion. There is ample evidence that insects are to be found in the atmosphere well above the surface. Apart from flying insects, creatures such as spiders can become airborne on strands of gossamer and be borne aloft in convective air currents. Glick (1939) reports in considerable detail the results of collecting insects from aircraft over the southern U.S. and Mexico. He found concentrations of insects of the order 1 per

2 cubic kilometers in the layer between 1000 ft. and 4000 ft. above the ground, with more widely spaced encounters up to four or five times the latter height. Although more recent data do not appear to have been collected, it is common for sailplane pilots to experience many types of insects impinging on the canopy or the leading edges of the wings at altitudes exceeding 10,000 ft. above terrain. Less commonly, birds feeding on insects carried aloft by thermals are observed at similar altitudes.

The radar cross-sections (σ) of the various insects listed in Table 4 (measured at wavelenths of 3.2 cm.) range from 0.01 cm^2 to 1.22 cm^2 for all but the locust which has a maximum σ value of 9.6 cm^2. The ability of any given radar system to detect radar cross-sections of these low values is a function of its design, its current performance, and the ability of the operator Ultra-sensitive radar systems such as the MIT Lincoln Laboratory radars at Wallops Island, Va. have reported minimum detectable cross-sections at 10 km. of $6 \times 10^{-4} cm^2$ for the X-band, 2.5×10^{-5} cm^2 for the S-band, and 3.4×10^{-5} cm^2 for the UHF radars (Hardy, 1966). The X-band radar is two orders more sensitive than required to detect the listed insects at a range of 10 km. and probably is functioning close to the limit of detectability. The majority of other radar systems in general use today are less sensitive. Some are not able to detect insects in the lower range of σ values. Tabulation of a large number of radar system characteristics has been published in classified documents by RAND. Major radar parameters for some airborne sets are listed in an article by Senn and Hiser (1963).

Insects are commonly found at surprisingly high altitudes. Swarms of butterflies and other insects are found in summer on 14,000-ft. mountain peaks in the Rockies. A few insects have been reported at over 25,000-ft. altitudes in the Himalayas.

Verification of insects as causing a particular blip on a radar scope is even more difficult than birds. However, this was accomplished as reported by Glover, et al (1966). Single insects were released from an aircraft and tracked by radar at altitudes from 1.6 to 3.0 km. and at ranges up to 18 km. Experiments of this sort and other studies involving clear atmosphere probing with high-power radars (Atlas, 1966; Hardy, 1966 and 1968) have led to valid conclusions that most of the dot echoes are caused by insects or birds.

Attention has been given by Browning (1966) to the determination of

Table 4

SUMMARY OF INSECT RADAR CROSS-SECTION DATA MEASURED AT 3.2 CM (from Hajousky et al, 1966)

Insect	Body Length MM	Body Diameter MM	σ_L cm^2	σ_T cm^2
Diptera				
Range Crane Fly-Timpula Simplex	13	1	0.30	0.02
Green Bottle Fly-Lucilia Ceasar	9	3	0.25	0.10
Hymenoptera				
Honey Bee (worker)-Apis Mellifera	13	6	1.00	0.30
California Harverter Ant-Pogonomyrmex Californicus	13	6	0.04	0.02
Coleoptera				
Convergent Lady Beetle-Hippodamia Convergens	5	3	0.02	0.01
Twelve-spotted Cucumber Beetle-Diabratica Duodecimpunctata	8	4	0.14	0.05
Lepidoptera				
Army Worm Moth-Cirphis Unipuncta	14	4	1.22	0.12
Alfalfa Caterpillar Butterfly-Colias Eurytheme	14	1.5	0.65	0.02
Orthopter				
Blue Winged Locust-Trimeratropic Dyanipennis	20	4	9.60	0.96
Aranedia				
Spider (unidentified)	5	3.5	0.10	0.06

the velocity characteristics of some clear-air dot angels. A 5.42 cm. pulse Doppler radar with a 1° beam elevated at 30° and rotating at 4 rpm was used in the study. A series of radar soundings spaced about half to one hour apart were obtained at 500 ft. altitude intervals up to 3000 ft. using range-gating techniques. Temperature, humidity and wind data were collected simultaneously with the radar soundings.

Three kinds of angel population were distinguished according to their mean deviation from the swarm velocity, their average vertical motion, their maximum relative velocities and their σ values. Atmospheric inhomogeneities or the presence of plant seeds appeared to be ruled out because of the small back-scattering cross-sections of individual angels (less than approximately 0.1 cm^2), their discreteness in space and velocity, their often quite large mean deviations (up to 4 m sec^{-1}) from a uniform velocity, and the fact that the only major upward velocities occurred after sunset, at a time when the lapse rate was becoming increasingly stable. The same data suggest insects as the likeliest cause.

<u>Satellites and space debris</u>

Some of the larger man-made objects in space (such as the Echo I and Echo II metallized balloons, Pegasus, and large boosters) have large radar cross-sections and can be detected by search radars. For example, Peterson, (1960) found that occasionally the radar cross-section of Sputnik II approached 1000 m^2. Such space objects at altitudes of around 120 mi. and with speeds of around 18,000 mph could appear as multiple trip echoes if they were detected on a search radar.

Fig. 6 illustrates the possible appearance of the track of a satellite on the PPI of a search radar. The figure assumes a satellite at 120 n. mi. altitude moving radially at a distance of 500 n. mi. from a radar with an unambiguous range of 200 mi. (The elevation angle of the satellite would be about 8° which is within the vertical coverage of many search radars.) When the satellite is at point A the echo is displayed on the PPI at point A', 400 mi. less than the actual range. As the satellite moves to point B its range closes to less than 450 mi. so the echo moves to within 50 mi. on the PPI. From B to C the range of the satellite opens to 500 mi. so the echo moves

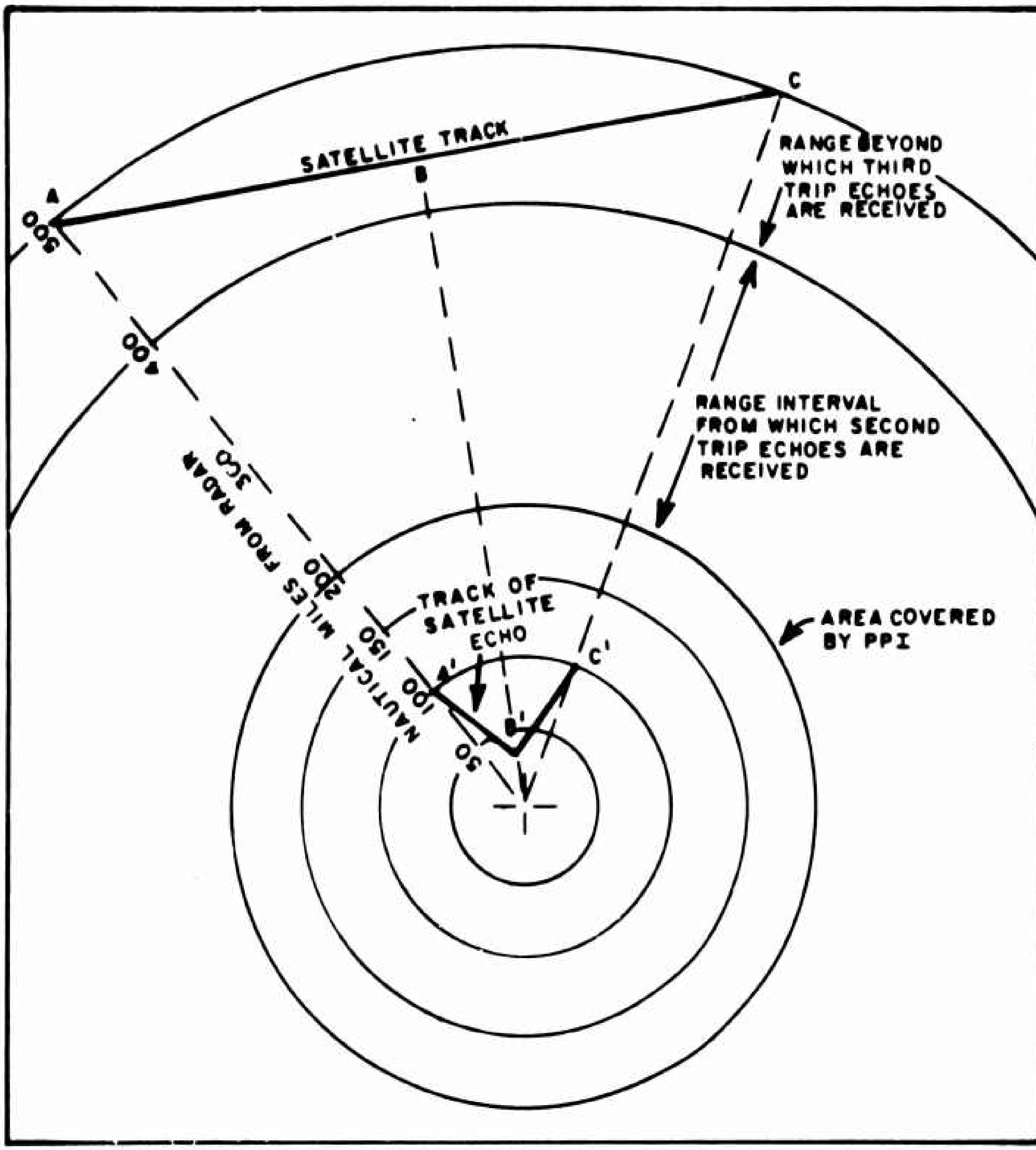


FIG. 6 TRACK OF MULTIPLE TRIP SATELLITE ECHO ON A PPI

out to 100 mi. again. An interesting feature of this example is that while the actual path length from A to C is 500 mi. the length of the echo track is only 140 mi. Thus, if the satellite was moving at 18,000 mph the echo would move only 140/500 x 18,000 or 5,040 mph. At the speed of 18,000 mph the satellite would move 5 mi/sec and take 100 sec. to move from A to C. It is obvious that the rotation rate of the antenna would have to be high to map the entire track of the satellite as it moved from A to C. An antenna rotating at 6 rpm would detect the satellite every 10 sec. and thus get an echo 10 times as the satellite moved from A to C. At slower rotation rates fewer points along the track would be displayed.

Detection of satellites by search radars would therefore result in high-speed echoes on the PPI. If the satellite were moving toward the radar the echo would move at the satellite velocity but would probably be detected for a shorter period since as it approached the radar it would rise above the vertical coverage of the radar beam.

Ionization phenomena

In 1906 J.J. Thomson showed that ionized particles are capable of scattering electromagnetic waves. Sources of ionized particles include lightning strokes, meteors, reentry vehicles, corona discharges from high voltage lines, and static discharges from high-speed aircraft. Ionospheric layers and the aurora are also ionization phenomena. These ionization phenomena or plasmas may under certain conditions produce radar echoes on the PPI of a typical search radar.

Plasmas resulting from lightning discharges return echoes which may be seen on the PPI if the operator is looking at the right spot at the right time. A number of investigators (Ligda, 1956; Atlas 1958a) have discussed the appearance of lightning echoes on the PPI. The echoes typically vary from a point to irregular elongated shapes up to 100 mi. or more in length.

A salient feature of lightning echoes is the short duration of the echo from a given lightning discharge. Since the echo lasts about 0.5 sec., it will be evident only on one scan.

The radar cross-section of the ionized column of plasma produced by lightning has been estimated by Ligda (1956) to be 60 m^2 depending on ion density within the plasma and on the wavelength of the radar illuminating the plasma. Electron densities of 10^{11}/cc are required for critical (100%) reflection of 3 cm. radar energy; only 10^9 electrons/cc are required with a 30 cm. radar. Thus, longer wavelength radars are more apt to detect lightning than the shorter wavelength radars. There is another factor which aids lightning detection at longer wavelengths. The longer wavelength radars detect less precipitation than the shorter wavelength radars. Therefore, a lightning discharge inside an area of light precipitation might be hidden within the precipitation echo on the PPI of a 3 cm. radar, while a 23 cm. radar might detect the lightning-produced plasmas but not the precipitation.

Confirmation that short-lived (one scan) echoes were caused by lightning was based on the fact that there were visual lightning discharges in the area from which the radar received the echoes. Atlas (1958a), however, estimated (from echo intensities and dimensions) that discharges may occur that are radar detectable, but are not visible to the eye. Whether or not there is visible lightning in the area of these short echoes, there will undoubtedly be precipitation areas in the vicinity. The exact distance from precipitation that lightning may occur has not been adequately studied. It is known that the probability of radar detection of lightning is greatest when the radar beam intercepts the upper levels (ice crystal regions) of thunderstorms. In a mature thunderstorm the ice crystal blowoff or anvil may extend many tens of miles downwind of the precipitation area. Atlas (1958a) illustrates a lightning echo some 10 to 20 mi. ahead of the precipitation echo but within the anvil cloud extending downwind from the storm.

In addition to short duration lightning strokes there is the longer-lived "ball lightning." Ritchie (1961) mentions the controversy surrounding ball lightning and also some of its alleged characteristics such as sliding along telephone wires, fences, or other metallic objects. Radar detection of ball lightning under these conditions is difficult since echoes of the metallic objects and the ground would tend to mask ball lightning near the surface.

Since search radars can detect echoes of very short duration returned by plasmas created by lightning flashes, there is no reason to assume that other plasmas could not be detected by search radars if the plasmas were sufficiently separated from other targets. The radar echoes would probably appear as point targets and if the duration were sufficient to compute a speed, it would correspond to that of the plasma. The possible range of speeds of plasma blobs cannot be given since so little is known about the phenomenon.

In addition to reflections of the radar pulse there is another source of signals from the lightning discharge, those that are radiated by the lightning discharge itself. These signals, called sferics, appear on the PPI as radial rows of dots, as one or more short radial lines, or as a combination of dots and lines (Ligda, 1956). Atlas (1958b) states that 10 cm. and 23 cm. radars are good sferics detectors while radars such as the 3 cm. CPS-9 have moderately low range capabilities in detecting sferics.

As with the lightning echo, the sferic duration is very short Atlas (1958b) found an average 480 μ sec. for 489 sferics measured during a severe squall line on 19 June 1957. As a result such sferic signals from a given lightning discharge would only be displayed on one scan of the PPI.

The aurora is a complex phenomenon caused by ionization of the upper atmospheric gases by high-speed charged particles emitted by the sun. Upon entering the earth's upper atmosphere, these charged particles are guided by the earth's magnetic field and give rise to

a luminous display visible only at night. The aurora occurs most often in the vicinity of 67° geomagnetic latitude. In the zone of maximum auroral activity, visual displays can be seen almost every clear night.

Increased auroral activity is found to follow solar magnetic storms. A direct correlation exists between sunspot activity and the intensity and extent of aurora. The increased auroral activity follows a solar disturbance by about one or two days, the time required for the charged particles to travel from the sun to the earth. During these times, auroras may be seen at latitudes far removed from the normal auroral zones.

Auroral displays occur in the ionosphere at altitudes ranging from 54 - 67 mi. The ionization which is seen as a visual auroral display is formed into long slender columns which are aligned with the earth's magnetic field. This formation results in strong aspect sensitivity which means that radar reflections occur only when the radar beam is approximately at right angles to the earth's magnetic field. Echo strength is proportional to the radar wavelength raised to the third or fifth power; consequently, most radar observations occur at VHF or lower UHF.

As a result only lower frequency UHF search radars within 1000 mi. of the Arctic or Antarctic Circles would be capable of detecting auroral echoes. The echoes would generally appear at true ranges of 60 - 180 mi. for a few minutes to several hours. The echoes would be mainly stationary and could be either distributed or point targets usually in the magnetic north azimuths in the northern hemisphere or magnetic south azimuths in the southern hemisphere.

Meteors are small solid particles that, when they enter the earth's atmosphere, leave an ionized trail from which radar echoes are returned. The majority are completely ablated at altitudes ranging from 50 - 75 mi. Visible meteors vary in size from about 1 gm. to about 1 μgm. The ionized trail produced by a 0.1 gm. meteor is miles long and only a few feet in diameter.

The meteor particle itself is far too small to be detected. Meteors are observed both visually and by radar by the trail of ionization they produce. Because of the distance and the small cross-section of the trail, meteor ionization can be detected by radar only when the trail is orientated at right angles to the radar beam.

Although most meteor echoes last no more than a fraction of a second when observed with VHF radar, a few echoes persist for many seconds. The duration of the meteor echo is theoretically proportional to the square of radar wavelength, and the power returned is proportional to the wavelength cubed. For these reasons, meteor echoes are seldom detected at frequencies above VHF.

Meteor echoes on a low frequency UHF radar usually appear as point targets with a duration of a few seconds or less. Ranges center around 120 mi.

Very, very infrequently meteors occur that are large enough to survive atmospheric entry. They usually produce a spectacular visual display, referred to as fireballs. Such meteorites are detectable by sensitive search radars operating at any frequency and at any angle to its path. Echoes appear as point targets with a duration of a few seconds. The true range would be less than 120 mi. and the range rate generally would be less than 20,000 mph.

Balloons

Balloons and instrument packages or reflectors carried by balloons can be detected by search radars. More than 100 balloons are released over the United States at least twice a day from Weather Bureau, Navy, and Air Force Stations for the measurement of upper atmospheric conditions. A number of these balloons carry radar reflectors as well as an instrument package, and some are lighted for theodolite (visual) tracking. Echoes from these point targets move at the speed of the wind at the altitude of the balloon. Balloon altitudes vary widely and may reach 100,000 ft. so that ground speeds vary from near zero to well over 100 knots. When a balloon bursts and the instrument package abruptly starts a descent which is normally slowed by

parachute, there could be an abrupt change in the behavior of the echo on the PPI. A balloon that had been rising in a direction away from the station would show the range gradually increasing. Then if it descended rapidly the range could appear to decrease which could be interpreted as a reversal of course.

"Chaff," "Window," and "Rope"

When radar was developed as a means for aiming searchlights and antiaircraft guns during World War II, countermeasures were promptly devised. What was needed was something inexpensive and expendable that would give a radar return comparable with the echo from the aircraft. Small metallic foil strips which act as dipole reflectors were employed. The strips are released from an aircraft, and they are wind-scattered which results in a cloud with a radar cross-section comparable to a large aircraft.

The terms "chaff," "window," and "rope" are used to designate particular types of materials. Chaff consists of various lengths of material. Chaff having the same length is called window. Rope is a long roll of metallic foil or wire designed for broad, low-frequency response.

Metallized nylon monofilaments have replaced metal foil in the construction of chaff and window. The nylon type is lighter, hence has a slower rate of descent, and is more compact. A typical package of X-band chaff is a cylinder 1 in. in diameter and 1.5 cm. (one half the 3 cm. wavelength) long. The cylinder contains approximately 150,000 filaments and weighs 6.5 gm. and forms a cloud with a radar cross-section of about 25 m^2. The filaments descend at about 2 ft/sec in still air at lower altitudes, so that if dispensed at 40,000 ft. they take about four hours to reach the ground. Turbulence causes the chaff cloud to grow and disperse, so that generally the signal becomes so much weaker that sometimes the chaff cloud cannot be tracked all the way to the ground.

Since chaff contains a large number of elements the radar signal is similar to that from precipitation. Also it moves with the wind at its altitude. Therefore, it is difficult to distinguish between precipitation and a cloud of chaff by briefly examining the PPI display. When chaff is distributed along a relatively extended path as opposed to only a point distribution, the echo is elongated and does appear to be dissimilar to precipitation.

Rope is a 60 - 80 ft. piece of narrow metallized material such as mylar. It is weighted at one end and has a drag mechanism at the other. When deployed it has a rate of descent about twice as fast as chaff so it would take about two hours to fall from 40,000 ft. to the surface. Usually a number of rope elements are deployed together so there will be some increase in the size of the cloud as it descends.

Smoke

Hiser (1955) reports detecting smoke from fires at a city disposal dump about 15 mi. from the site of a 10 cm. search radar. The radar echo from the smoke plume was evident on the PPI extending in a northeasterly direction to a range of 50 mi. Goldstein (1951) mentions a case where an airplane was directed to an echo observed by a 10 cm. radar. Only several columns of smoke from brush fires were found. Smoke particle size and concentrations are so small that one would be highly skeptical about echoes from the smoke itself. The returns may arise from refractive index discontinuities at the boundaries of the smoke plume. Plank (1956) suggests that echoes from the vicinity of fires may be from either particles (neutral or ionized) carried aloft by convective currents or from atmospheric inhomogeneities created by the fire.

Distant Ground Return and "Angels"

Local terrain features and, at sea, the ocean surface are detected by radar. The range to which such clutter is detected is a function of antenna height, elevation angle and beamwidth, and the distribution of temperature and humidity along the propagation path.

Since normal ground clutter is present day after day, radar operators become familiar with it and may even use some prominent points to check the azimuthal accuracy of the radar. There are circumstances in which distant, rarely detected terrain features or surface objects return echoes to a radar. The phenomenon referred to as "angels" is also included in this section since at least some of the angels appear to be distant ground return that is detected by reflection or forward scatter of the radar beam by atmospheric inhomogeneities.

To investigate the phenomena of distant ground return it is first necessary to review some of the fundamentals of the propagation of electromagnetic radiation through the atmosphere. The interested reader can find a comprehensive treatment of tropospheric radar propagation in a book on radio meteorology by Bean (1966) which covers in detail the topics in the following brief review.

In a vacuum, electromagnetic energy is propagated in straight lines at the velocity of light, 3×10^8 m/sec. This constant is usually designated by the symbol "c." In a homogeneous medium, the direction of propagation remains constant, but velocity (V) is reduced and

$$V = \frac{c}{\sqrt{\mu\kappa}} \qquad (1)$$

where μ is the magnetic permeability of the medium and κ is its dielectric constant and

$$\sqrt{\mu\kappa} = n = \frac{c}{V}$$

where n is the index of refraction.

When electromagnetic wave energy encounters a surface of discontinuity in refractive index in a medium, the wave is partly reflected and partly refracted.* The angle of the incident ray (θ) is related to the angle of the refracted ray (θ') by the equation:

$$\frac{\sin\theta}{\sin\theta'} = \frac{n'}{n} \qquad (2)$$

where θ and θ' are the angles of incidence and refraction respectively in the first and second medium, and n and n' are the values of the refractive index for the first and second medium respectively.

The ray is always refracted towards the medium of higher refractive index. A portion of the energy will also be reflected in the same plane and at an angle equal to the angle of incidence if the energy encounters a sudden change in the refractive index; this is a partial reflection. Total reflection occurs when the angle of incidence exceeds a critical value given by (with $n_1 < n_2$):

$$\theta_1 = \frac{\sin^{-1} n_1}{n_2} \qquad (3)$$

In the atmosphere, discontinuities in refractive index sharp enough to cause reflection of the incident wave back to the radar are believed to exist on occasion. Because of the difficulty in making suitable measurements of the physical factors involved, some uncertainty attends the understanding of this mechanism under practical conditions. Detailed discussion of this aspect of propagation is deferred until later where radar 'angels' are described. In the present context, discussion of the effects of refractive index inhomogeneities will be confined to refraction.

*For a more complete discussion of atmospheric refraction of electromagnetic rays, see Section III, Chapter 5 and Section VI, Chapter 4/ Note, however, the difference in the factors contributing to the refractive index at radar and at optical frequencies.

Where the refractive index gradient is changing continuously as is normally the case in the natural atmosphere as the height above the earth's surface increases, a ray of electromagnetic energy will follow a curved path. The change of direction that this produces may be evaluated by reference to Snell's law by the expression

$$n_h(a + h) \cos \beta = n_s a \cos \beta o \qquad (4)$$

where n_h is the refractive index at height h, n_s is the refractive index at the surface, a is the radius of the spherical earth, β is the ray elevation angle at height h and βo is the ray elevation angle at the earth's surface (See Fig. 7).

A most important consequence of this is that *the effects of a vertical gradient of refractive index are most apparent at low (10° or less) angles of elevation.*

Where the refractive index gradient is constant ($n_h = n_s$) or varies regularly, the curvature of the path of rays of radar energy may be readily determined by reference to the foregoing expressions. In more complicated conditions more sophisticated techniques are available for tracing the path of such rays.

In terms of the real atmosphere, at radar frequencies the refractive index varies as a function of pressure, temperature, and water vapor content. An equation relating the various parameters as given by Smith (1953) is:

$$(n-1)\ 10^6 = \frac{77.6P}{T} + \frac{3.73 \times 10^5 e}{T^2} \qquad (5)$$

where P = total pressure (millibars)

T = absolute temperature (degrees Kelvin)

e = partial pressure of water vapor (millibars)

When the available data are given in terms of relative humidity, e may be replaced by e_s R.H., where e_s is saturation vapor pressure at the pressure and temperature of interest and R.H. is relative humidity expressed as a decimal.

For convenience, the left hand side of the equation is commonly designated N (refractivity) and is expressed in N-units, i.e., $N = (n-1)\ 10^6$.

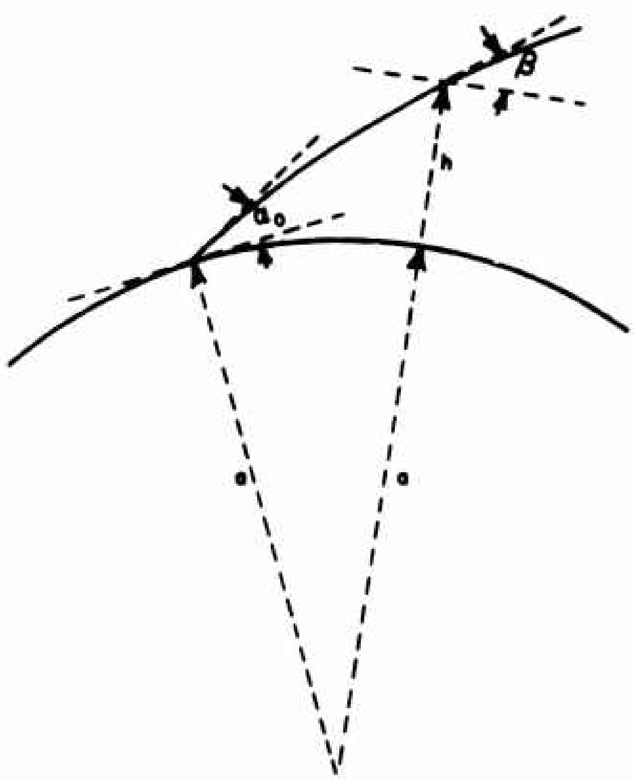


FIG. 7 CURVATURE OF ELECTROMAGNETIC WAVES WITH HEIGHT

Values of N are conveniently derived from meteorological parameters by the use of tables or nomograms, such as those given by the U.S. Navy (1960).

At sea level, a typical value of n is 1.00035, i.e., the refractivity is 350 N units. But depending upon pressure, temperature and humidity the sea level refractivity may range from 250 to 450 N units.

Since pressure, temperature, and water vapor normally decrease with height the refractivity normally decreases with altitude. In a 'standard' atmosphere, typical of temperate latitudes (with a thermal lapse of 2°C/1000 ft. and uniform R.H. of 60%, the gradient (lapse rate) of refractivity is 12 N-units/1000 ft. 39 N. km^{-1} in the lower levels. For a constant gradient of this magnitude, a ray will have a curvature of about 1/4th that of the earth's surface (the radar horizon in this case is about 15% further than the geometrical horizon). For short distances the geometry is equivalent to straight-line propagation over an effective earth with a radius 4/3 as large as the true earth.

A device frequently used to facilitate the consideration of propagation geometry and radar coverage takes advantage of this fact. If a fictitious earth radius is adopted that is 4/3 the earth's true radius, radar rays in the standard atmosphere may be drawn as straight lines, which will preserve the same relationship to the redrawn earth's surface as is the case in reality.

In atmospheres having different constant gradients of refractivity appropriate factors may be applied to the earth's true radius to accomplish a similar result. Typical values are given in Table 5.

Table 5

Effective earth radius for several atmospheres

Atmosphere	Typical $\frac{dN}{dz}$	Effective earth radius for typical $\frac{dN}{dz}$
Standard	-12 N-units/1000 ft.; -39 km^{-1}	1.33 actual radius
Subrefractive	+10(> 0); +33 km^{-1}	0.82
"Normal"*	-15(0 to -24); -50 km^{-1}	1.47
Superrefraction	-30 (24-48); -100 km^{-1}	2.68
Trapping	-48 (or greater); -157 km^{-1}	∞ (or negative; i.e., concave earth)

*For an average temperate zone climate; northern climates (e.g. England) tend to be "standard," tropical climates tend to be near-superrefractive (e.g. -80 km^{-1}).

It is important to recognize the limitations of this device, for even in standard atmospheres initially horizontal rays rapidly reach higher atmospheric levels, at which the refractivity gradient can no longer be represented by the same constant. Again, as will be discussed below, atmospheric conditions frequently depart from the "standard" conditions. The effect of variation in the refractivity gradient on the curvature of radar rays is shown in Fig. 8. Apart from showing the range of curvatures in atmospheres having constant refractivity gradients, this figure indicates the way in which rays can be deflected in passing through atmospheric layers. More specifically, the deflection of a ray in milliradians ($\Delta\tau$) in passing through a layer with constant N-gradient is given by:

$$\Delta\tau = \frac{N_B - N_T}{500\,(\tan\beta_B + \tan\beta_T)} \qquad (7)$$

where the subscripts B and T refer to the bottom and top of the layer respectively. The values of β are determined at each level in terms of β_0, N_s (surface refractivity), N_h (refractivity at height h) and h, using Snell's Law (equation 4).

Procedures based on these relationships may be used to trace the path of rays to determine the detailed effect of refraction on radar propagation under any given condition of atmospheric stratification.

The broad pattern of refractive effects, however, is as follows:

Where the general refractivity gradient lies between 0 N-units/1,000 ft. and 24 N-units/1,000 ft. (100 km^{-1}) propagation is described as *normal*. Refractivity gradients less than 0 N-units/1,000 ft. are *subrefractive* and cause upward bending of radar waves with a reduction of distance to the radar horizon. Such conditions may occur where the temperature lapse rate is well above average, or where the atmosphere is drier at lower levels than aloft.

Where the refractivity gradient exceeds 24-N units/1,000 ft. conditions are said to be *superrefractive* and radar waves curve down

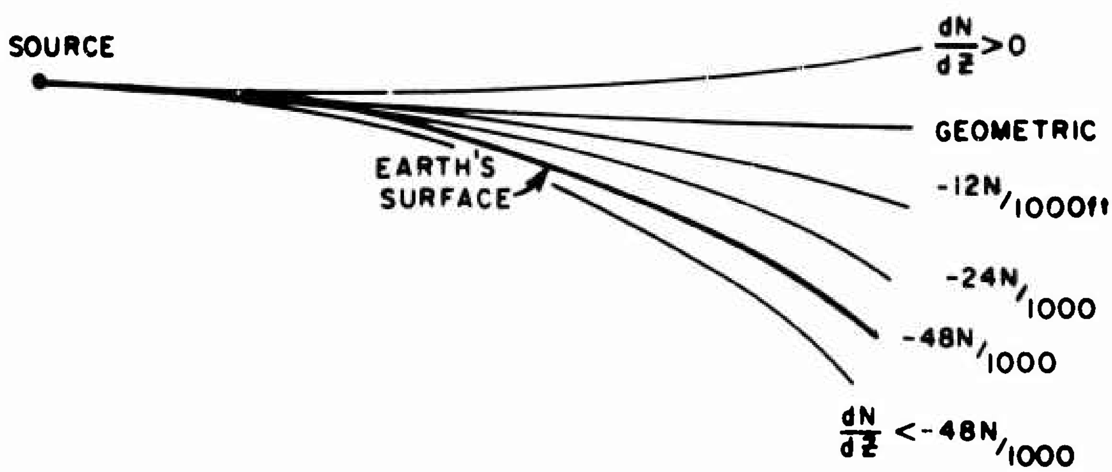
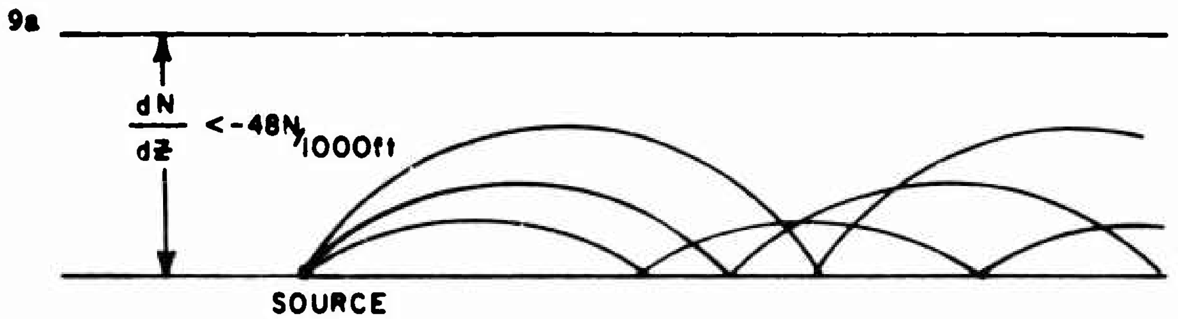
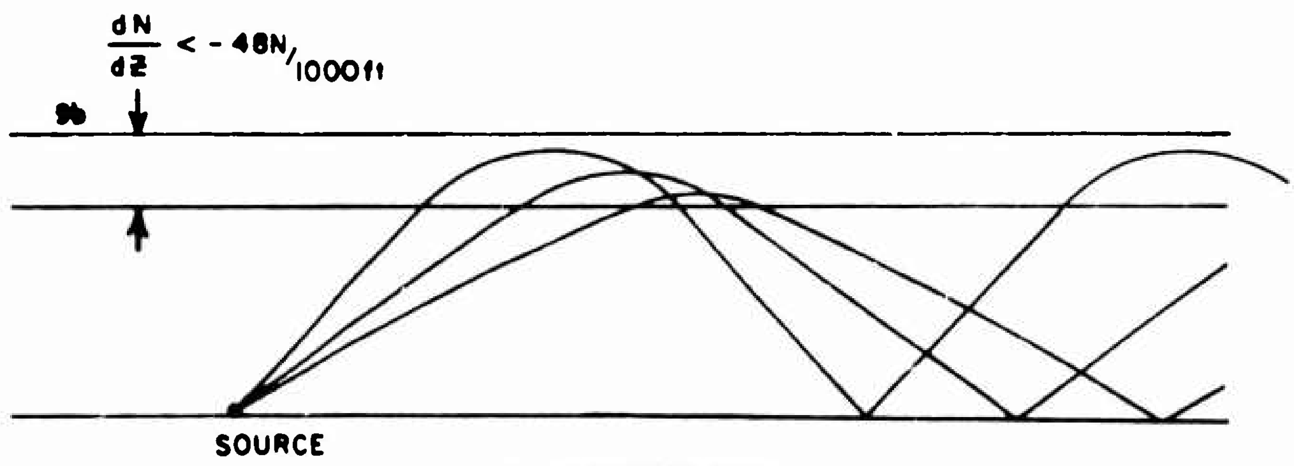


FIG. 8 VARIATIONS IN CURVATURE WITH DIFFERENT REFRACTIVITY GRADIENTS



a. SURFACE DUCT



b. ELEVATED DUCT

FIG. 9 RAY PATHS THROUGH 'DUCTS'

more strongly. Such conditions result from thermal inversions, i.e., where temperature increases with height, or where the decrease of water vapor content with height is excessive.

For refractivity gradients greater than 48-N/1,000 ft. (157 km^{-1}), the ray curvature will be greater than that of the earth's surface and trapping is said to occur.

This condition gives rise to marked anomalies in propagation and, provided the layer through which such a gradient occurs is deep enough, the radar energy will be guided within a duct bounded by the earth's surface and the upper level of the layer. In such cases, exceptionally long detection ranges are achieved, well beyond the normal radar horizon (See Fig. 8). Where a marked negative refractive gradient occurs in a layer adjacent to the ground, a surface duct is formed (Fig. 9a). An elevated layer of strong negative gradient can also produce ducting (Fig. 9b).

Surface ducts are commonly caused by radiative cooling of the earth's surface at night, leading to a thermal inversion in the air near the surface. In this case, the extreme refractivity gradient is mainly due to temperature effects and such ducts can occur in quite dry air. Where humidity at the surface is higher than usual and falls off rapidly with height, a strong negative refractivity gradient is also established. Evaporation from water surfaces or wet soil can produce these conditions and a particularly common example occurs in warm dry air from the land when it is advected over the sea. This type of duct is commonly found in tropical areas, where temperature and humidity both decrease with height; the inversion type of duct is more common in temperate and artic areas (Bean, 1966).

Elevated layers of extreme refractivity gradient are caused by similar meteorological mechanisms but often occur on a somewhat broader scale. Certain areas of the world are particularly prone to such layers; the California coastal area is a good example. Plate 66 (Blackmer, 1960) shows an example of the PPI during a trapping situation off the California

Coast. In this case echoes were presented on the PPI on second and third sweeps but could be correlated with islands and mountainous terrain. Elevated layers such as this are commonly found in the south-east (northeast at S latitudes) quadrants of trade-wind anticyclonic systems.

The anomalous propagation to which such irregular refractivity conditions give rise is of considerable significance to the problem of target identification and false targets. In the first place, the whole basis of the radar technique depends upon knowing the direction in which the radar energy is propagated. For normal practice, propagation must be close to rectilinear. When the radar energy is being strongly curved, information on a target's location derived from the position of the radar antenna can thus be highly erroneous. Again, echoes may be received from the ground or from other targets that are not normally within the range of the radar or within its 'field of view' at any given antenna elevation. Ground echoes from beyond the normal radar horizon are cases in point.

An especially significant condition arises when the antenna is elevated in a direction which is near a critical angle for trapping or ducting. In this case, while much of the energy may be propagated in a direction approximating that intended, because of the finite dimensions of the radar beam, some energy may be severely refracted. This is illustrated diagrammatically in Figure 10.

With such a mechanism an aircraft could be tracked fairly accurately, but in addition, echoes could be received from the ground (intermittently if the surface reflectivity or propagation conditions are variable as might be the case in areas of thunderstorms). Such echoes would be displayed as though they were due to targets seen at the angle of elevation of the antenna, and thus at heights which would depend upon their range. A great variety of such possibilities can occur depending upon the geometry involved, the refractive conditions, and the nature of the terrain.

The range of possibilities is further extended if the distribution of radar energy in the side lobes is taken into consideration. With a side lobes strength 30dB below the main beam (a factor of 1000 in power), a side lobes target will yield a return equal in strength to the main beam return of an identical target at a range 5.6 times greater (the 4th root of 1,000). Thus a target detectable at 100 mi. in the main beam might be detected by the (first) side lobes at a range of up to 18 mi.

Anomalous propagation of the type described is also significant in determining the distribution of energy within the envelope of the main beam, particularly in broad vertical beam systems. At low angles some energy within the beam impinges on the earth's surface near the radar and is reflected, still within the envelope of the beam. Because the path followed by such energy is necessarily longer than the direct path and because of the wave nature of the energy, in-phase and out-of-phase interference will occur, leading to a vertical lobe structure in the beam envelope (see Fig. 10). Anomalous propagation conditions can readily produce variations in the normal distribution of energy within the beam due to this mechanism and thus can easily lead to unexpected variations in signal intensity from distant targets.

It is important to recognize the difficulties that are inherent in establishing whether propagation conditions are anomalous in certain cases. Where the gradient of refractivity extends uniformly over large horizontal areas, there is little difficulty in determining the situation either from conventional meteorological data or from the manifestation of the anomalous performance of the radar itself (for example, the detection of ground clutter to abnormally large ranges). In some cases it is possible to infer, with some confidence, from the meteorological conditions (especially if data on the vertical profile of temperature and humidity are available) that anomalous propagation is *not* present. In many cases, however, the causative conditions may be very variable in space and time, and it is then difficult to be at all confident

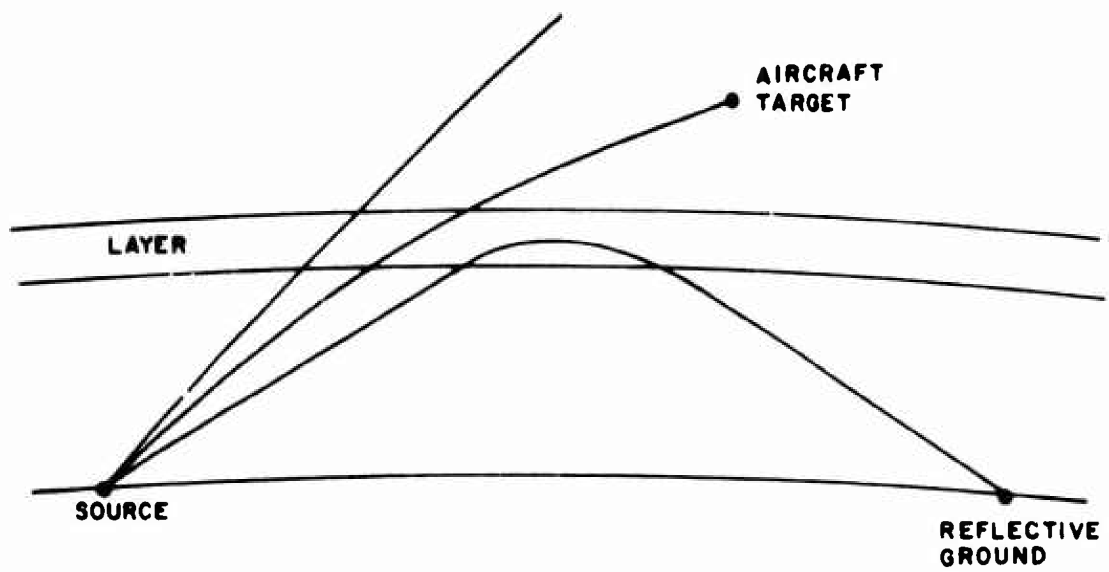


FIG.10 DUCTING OF A PORTION OF THE RADAR BEAM. BOTH SURFACE AND ELEVATED TARGET ARE DETECTED

about the nature of propagation at any particular time or in any p ticular place. Even if timely radiosonde data are available from a nearby location, the information they provide on the thermal and humidit gradient is often inadequate for the assessment of the refractive n-ditions. In particular, special experimental observations have s that shallow layers of abnormal refractivity commonly occur eithe close to the surface or at various levels aloft.

It is often possible to infer only the likelihood or improbability of anomalous propagation conditions by reference to the general meteorological conditions that prevail. Thus one would expect normal propagation in the daytime in a well-mixed, unstable airstream with moderate winds over a dry surface, while expecting marked superrefraction over moist ground during a calm clear night following the passage of a front that brought precipitation in the late afternoon.

Localized conditions favorable for superrefraction are also caused by showers and thunderstorms (Ligda, 1956). The cold downdraft beneath thunderstorms can cause colder air near the surface than aloft while evaporation from the rain and rain-soaked surface, causes locally higher humidities.

In addition to the detection of distant ground targets by refraction of the radar beam, there is the possibility of reflection or foward scatter of the beam to ground targets. Whether or not layers that would reflect the beam to the ground would also be detected by the radar has been part of the controversy concerning the nature of invisible targets in clear air. These so-called "angel" echoes have been observed since the early days of radar (Plank, 1956; Atlas, 1959 and 1964; Atlas, 1966a). Detailed case studies of selected angel situations illustrate the difficulty of determining the nature of the targets causing the angel echoes. For example, Ligda and Bigler, (1958) discuss a line of angel echoes coincident with the location of a cloudless cold front. They discuss the likelihood that the line was due to differences

in refractivity between the two air masses or to flying debris, leaves, paper, small twigs, birds, insects, etc., carried aloft by turbulence during the frontal passage. Although surface weather instruments recorded a drop of 13°F in less than an hour, this sharp temperature change together with the change in both vapor pressure and atmospheric pressure did not appear to be sufficient to cause gradients of refractivity of sufficient strength to produce the observed echo line. In spite of this difference between refractivity gradients based on surface observations (of pressure, temperature, and moisture) and those required to explain the source of the echo, Ligda and Bigler found serious objections to any hypothesis other than that the echo was due to refractivity gradients. They mention the need for instruments capable of measuring sharp refractivity gradients.

Atlas (1959) studied in detail a situation at Salina, Kans. on 10 September 1956 where cellular and striated echoes covered much of the PPI to ranges of 85 mi. He concluded that the echoes were due to forward scatter from a patterned array of refractive index inhomogeneities to ground targets and back. Recently Hardy and Katz (1968) discussed a very similar radar pattern. They concluded that insects were responsible for the echoes and that cellular pattern of insects was due to atmospheric circulation. Atlas (1968c) agreed that insects may be responsible for some echoes but that the forward scatter explanation is valid in other instances.

Investigations of angel echoes with high-power, high-resolution radars at three different wavelengths have made it possible to learn much about the nature of targets producing various types of angel echoes. Simultaneous observations at 3 cm., 10.7 cm., and 71.5 cm. with the ultrasensitive MIT Lincoln Laboratory Radars at Wallops Island, Va. have been described by Hardy, Atlas, and Glover (1966), Atlas and Hardy (1966a), and Hardy and Katz (1968a). They found two basic types of angel echoes: dot or point echoes and diffuse echoes with horizontal extent. The dot angels are incoherent at long ranges or when viewed with broad beams but are discrete coherent echoes when viewed by a radar with high resolution. They may occur in well defined layers and may have movements different from the wind at their altitude. Their cross-sections and wavelength dependence are consistent with radar returns to be expected from insects. Since no other explanation fits all the observations of these dot angels, it is concluded that the targets are insects.

Extensive diffuse echo layers have been noted at a variety of heights and sometimes exhibit an undulation or wave motion. The height of these layers coincides with levels at which refractive inhomogeneities may be expected, e.g., at the tropopause. It can be shown theoretically (as summarized by Hardy (1968b) that the measured radar reflectivity of such layers accords well with the theory of the scattering of electromagnetic energy by dielectric inhomogeneity due to Tatarski (1966). The reflectivity η is related to wavelength λ and the coefficient C^2, which describes the degree of refractive inhomogeneity due to turbulence, by the expression

$$\eta = 0.39\ C_n^2\ \lambda^{-1/3} \qquad (10)$$

from which it will be seen that such layers are more likely to be detected by radars operating at shorter wavelengths. Although, because this simple relationship does not apply in the dissipation range of the turbulence spectrum the largest values of η occur at about 5 cm (Atlas 1966b). These phenomena have been much studied recently in connection with the detection of clear air turbulence. (Hardy, 1968b; Ottersten, 1968: and Atlas, 1968b). It is concluded that such turbulence may be detected with ultra high performance radars but only when well marked. (Note that the significant physical feature detected, i.e., the dielectric inhomogeneities, is caused in these cases by the turbulent condition of the atmosphere.)

Radars of the type normally used for tracking and surveillance are unlikely to detect such layers. On the other hand it has been suggested that on occasion at low levels where marked intermixing of dry and moist air is present, dielectric inhomogeneities will be sufficiently marked and be present in sufficient quantity to produce detectable echoes with radars of relatively modest performance.

Measurements made by Atlas (1953, 1959) and others indicated that atmospheric layers occasionally exist having power reflection coeffieients, at normal incidence, of 10^{-14} or greater (i.e., 140 db attenuation). The power reflection coefficient of such layers would be greatly magnified if the radar energy impinged on the layer at a small grazing angle. The increase is roughly proportional to the 6th power of the cosecant of the grazing (i.e., elevation) angle. Thus at a grazing angle of about 10 mrad, the reflected signal would be as high as 10^{-2} (a 20 db attenuation). Under actual atmospheric conditions the partially reflected signal of ground objects for example, would be expected to be detectable only at grazing angles (and thus, initial elevation angles) low enough to produce return signals above the noise threshold of the radar receiver. This would produce a "forbidden cone" effect, where no such anomalous signals would be detected closer than a certain range (because of elevation angle, range relation of a layer at a constant height); this has been actually observed in several cases (see Section III, Chapter 5).

It is conceivable that there could be rare occasions when only isolated atmospheric inhomogeneities existed or when the inhomogeneities were such that only the most reflective ground targets were detectable. In such situations only one or two unusual ground targets would appear on the PPI. Levine (1960), in a discussion of mapping with radar, points out how certain combinations of ground and man-made structures act as 'corner reflectors' and return a much stronger signal to the radar than is returned by surrounding features. The sides of buildings and adjacent level terrain, or even fences and level terrain, constitute such reflectors. He states that in areas where fences and buildings are predominantly oriented north-south and east-west, the 'glint' echoes from the corner reflector effect appear at the cardinal points of the compass and have therefore been called a "cardinal point effect." In addition, different types of vegetation have different reflectivities and these vary further according to whether they are wet or dry.

From the above discussion it is obvious that the identification of targets as being ground return due to forward scatter or reflection

is difficult in any but the most obvious situations. Still it should be realized that situations do occur when only very localized areas of ground return may be detected and due to the detection mechanism the location of the intersection of the radar beam with the ground may vary from sweep to sweep of the radar antenna. The problem of verifying whether the target is ground return is greatly complicated by the fact that measurements of refractivity gradients cannot currently be made in sufficient detail around the radar site to describe with precision the medium through which the radar beam is being propagated.

Radio Frequency Interference

During the past 15 years, electromagnetic compatibility (EMC) has emerged as a new branch of engineering concerned with the increasing problems of radio frequency interference (RFI) and the overcrowding of the radio frequency spectrum. The EMC problem is increasing so rapidly that considerable engineering efforts are included in the design, development, RFI testing and production of all new electronic equipment from the electric razor and TV set to the most sophisticated of electronic equipments, such as computer and radar systems. This is true for entertainment, civil, industrial, commercial, and military equipment. The problems are compounded not only because the frequency spectrum is overcrowded, but much earlier generation equipment, which is more susceptible to and is a more likely source of interference, is not made obsolete or scrapped. New generation equipment is potentially capable of interaction problems among themselves, as well as playing havoc with older equipment. Each year sees new users bringing new equipment into the frequency spectrum: such as UHF television, garage door openers, automatic landing control systems, city traffic management and control systems, and a vast array of new electronic devices being introduced into tactical and strategic defense systems.

RFI contributes to the information displayed on radar scopes. It is caused by the radiation of spurious and/or undesired radio frequency

signals from other non-associated electronic equipment, such as navigational aids, data processing computers, voice communication systems, other radars, and from more common sources, such as ignition and electric motor control systems. RFI can also be emitted from the radar system's own components, causing self-induced interference.

Much interference may be sporadic, producing only a short lived 'echo.' There may be instances, however, when the interference occurs at regular intervals that could nearly coincide with the antenna rotation rate so that the spurious 'echo' might appear to be in approximately the same position or close enough to it that the operator would assume there was a target moving across the scope.

Radio frequency interference can enter the radar system in many places:

(1) In the transmitter where it can affect the stability and fidelity of the transmitted output pulse waveform;

(2) In the receiver local signal-generating and amplifying circuitry where its effects can be similar to the transmitter perturbations;

(3) In the external transmitter/receiver space link where the interference effectiveness depends upon its intensity, frequency, power level, direction of arrival and signal spectral characteristics.

External interference entering on the link through the antenna input is the most common of these possible interference sources. Plate 67 shows some of the more easily recognizable radio frequency interference patterns from other radar systems. This type of interference

considerably reduces the effectiveness of the radar, but this type of interference, taken alone, is usually readily identifiable by operating personnel. This might not be as true when it occurs in conjunction with extraordinary meteorological, propagation, and equipment degradation phenomena.

The photographs in Plate 66 are time exposures of the PPI. The camera shutter is left open for a full rotation of the antenna so the photograph is generated by the intensity of the cathode ray tube electron beam as it rotates with the antenna. This is in contrast to an instantaneous photograph that would be brightest where the trace was located at the instant of exposure and, depending on the persistence of the cathode ray tube, much less bright in other regions. While the interference in these photographs appears as lines it would appear as points at any given instant. The lines are generated by the time exposure as the points move in or outward along the electron beam. The photographs also show precipitation echoes. Examination of the photographs shows that the interference does not mask the larger precipitation echoes to any appreciable extent but might mask small point targets.

A radar receiver has a limited bandwidth over which it will accept and detect electromagnetic signals. In this acceptance band, the receiver reproduces the signals at the receiver output and displays them on the radar presentation display. Thus any interfering signals that fall within this band will be detected and displayed by the very sensitive receiver. In an S-band (2ghz) pulse radar, the typical bandwidth of the receiver will be 20 - 50 ghz. Any weak signals in this frequency band will be detected. Even out-of-band signals can interfere if they are of sufficient signal intensity to overpower the receiver out-of-band rejection characteristics. For instance, a very strong out-of-band signal of 10 watts might be typically attenuated by the receiver preselection filter by 60 db, reducing it to a signal of -20 db. To the radar receiver,

this can still be a powerful signal, as it might have a sensitivity of displaying signals as weak as from -50 to -80 db or less. It is also likely that the out-of-band interference will be derived from the nonlinear interaction of the desired return signal and the out-of-band interfering signal. The resulting interaction (mixing) of these signals in the receiver can generate still weaker intermodulation products that fall within the passband of the system circuits so that they are displayed. Spurious responses can occur at other than the frequency to which the radar is tuned because of inadequacies in the rejection of the unwanted frequencies in the receiver. The inadequacy is caused by insufficient out-of-band filter rejection coupled with a high level of RFI.

Increasingly more powerful transmitters and more sensitive receiver radar systems need even greater relative suppression of unwanted emission, to prevent the absolute level of out-of-band interference from rising to intolerable levels, thus causing interference to and from other electronic systems.

Even if normally operating radars are not affected by this interference most of the time, the degradation of the radar components or of nearby systems can cause the temporary increase in interference at the radar site. Radar personnel are continually concerned with this problem. Such acts as opening an electronic cabinet can cause the local RFI to increase sufficiently to create an RFI nuisance to the radar system.

Each radar system has been designed to fulfill a single class of target tracking function, being optimized to provide proper and reliable target data a high percentage of the time. However, all systems, including radar systems, have their limitations. Thus, it must be recognized that there will be times when other systems will interfere, component parts will either gradually degrade or catastrophically fail, propagation and meteorological conditions will deviate far from the normal environment, and maintenance and operating personnel will

occasionally fail to function effectively. For all radar and other electronic systems, an increasing amount of effort is expended to reduce the occurrence of these degradations or failures and to minimize their effects.

Lobes and Reflections

Because of radar engineering design limitations, it is not possible to direct all of the transmitter energy into the main antenna beam and small but measurable amounts of energy are transmitted in many other directions. Similarly, energy can be received from such directions, in what are known as the side lobes of the antenna, and can give rise to erroneous directional information. Particularly complicated situations arise when side lobe problems are associated with building or ground reflection mechanisms. For example, if a radar antenna is radiating 100,000 watts peak power in the main beam, 100 watts can be simultaneously radiated from a -30 db side lobe in another direction. Fig.11 (adapted from Skolnik, 1962) shows a radiation pattern for a particular parabolic reflector. Note that if the main beam is radiating 100 Kw, the first side lobe, the first minor and the spillover lobe radiate about 100 watts. This 100-watt radiation will be reflected from large targets in this side lobe heading but will be shown on the PPI as having the same bearing as the main beam of the antenna. This display of a false target is called a ghost. In this particular instance two targets having identical radar cross-sections would appear as returns of equal intensity if one were in the main beam and the other in the side lobe but 5.6 times closer to the radar.

Highly reflective targets can often be detected in the side lobes. Thus a single large target detected in the numerous side lobes can be displayed in a number of places simultaneously. Since, in radar displays, target echoes are represented as being in the direction in which the antenna is pointing, not in the direction from which the energy is returning at the time of the detection, side lobe echoes from

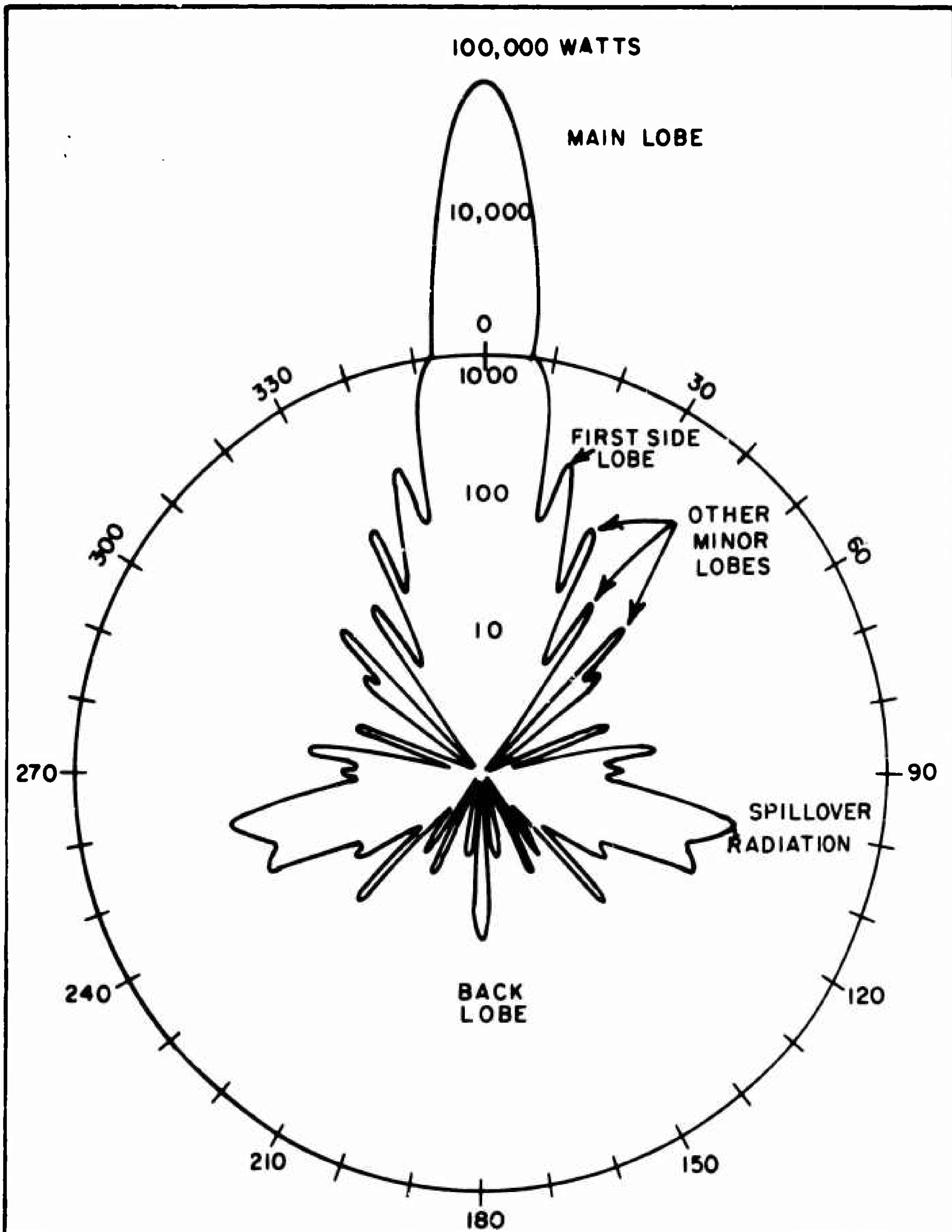


FIG. 11 LOBE PATTERN OF A RADAR ANTENNA

a single target can be shown as a collection of false targets. Such target outputs from side lobe returns are generally systematically located in the display relative to the main beam return signal. Therefore, in general, side lobe return signals are readily identifiable by the operator and will tend to cause obliteration of other nearby target returns. Side lobe return signals usually bear a fixed relationship of adjacent blips on an arc about each side of the main target return. This is a common problem in ship radars where another ship is being scanned broadside. The highly reflective ship might have a return signal that will occur at the true range of the ship, but will be contained in an arc exceeding 10° or 15° instead of a single narrow blip.

Detection from vertical side lobes can cause strange effects when "radio dusting" is present. Many radars are constructed so that the antenna cannot be pointed at very low elevation angles, in order to avoid the most severe anomalous propagation effects or, more often, to avoid ground reflections. Assume, for example, a radar with a beam width of (nominally) 1°, having a minimum at say 1.5° and a side lobe at 2°. Assume also that the antenna is constrained to elevation angles of 1.5° or greater. If a surface duct is present, the strongest signals would be attained by pointing the antenna (and the main beam) at an elevation angle of 0°, but this cannot be done. However, ducted targets could be detected with the first (vertical) side lobe, and in this case the maximum AP signals (ducted) would be attained at an apparent elevation angle of 2° (so that the main side lobe was at 0°), and the intensity of these false target signals would decrease or even disappear if the antenna were lowered to its minimum setting of 1.5°. This sort of behavior has apparently led some investigators of specific UFO incidents to discount the possibility of anomalous propagation as the source of unknown radar targets.

Smith (1962) discusses the effects of side lobes on observed echo patterns during thunderstorms and periods of anomalous propagation. In

both situations echoes were observed extending from the surface up to 70,000 ft. (the upper limit of the RHI scope). Before these vertical protrusions to high altitudes were observed during anomalous propagation conditions when the echoes were known to be from ground clutter, it was not realized that they were from side lobes. As a result, the side lobe echoes had not been recognized when measuring thunderstorm heights and reported heights were much too great. On the RHI side lobe, echoes took the form of narrow echo protrusions above the location of strong targets. These protrusions were often segmented due to nulls between side lobes, but in some cases were continuous.

One effect of such lobes is that when the antenna of a search radar is elevated (so that at longer ranges no ground return should be evident) ducted side lobe radiation results in echoes on the PPI. Without understanding what is happening, the operator would logically assume a strong target at high altitudes.

Angle of arrival measurements by a radar, like other measurement devices, will be limited in accuracy by noise and interference. Other limiting factors can be the reflection caused by the wave characteristics of electromagnetic radiation. Reflections from the ground in front of the antenna system or from a nearby building or mountain can be minimized by proper antenna location. These effects can seldom be reduced to zero and are detrimental to an extent that depends on the antenna lobe pattern, geographical, and extraordinary meteorological conditions, thus causing residual reflection problems.

Another phenomenon explaining strange and erratic radar returns has been observed with echoes occurring at locations where no targets are to be found. Analysis of these observations shows that the echoes are from ground or airborne objects which are being detected by radiation reflected from mirror-like plane surfaces of vehicles or buildings in the neighborhood of the radar. If the reflector is moving, then the reflected ground target behaves like a moving target.

It changes its apparent distance and direction relative to the radar. The double reflecting return echo is shown in the PPI display in the direction at which the first reflecting surface is found. The echo may, however, be displayed at a point at which there is no actual target. Moving objects, such as automobiles or other objects capable of reflecting electromagnetic waves may be obscured on the PPI by ground clutter so they are not identified. It is obvious that ghost echoes can show movement which is not possible with real vehicles. Many unusual PPI observations have been explained in this manner.

Mechanisms of multiple reflections which serve to produce ghosts are illustrated in Fig. 12. These involve specular reflection from the first target, effectively deflecting a significant amount of radar energy to a second target at a different azimuth, which is oriented so as to reflect most of the radiation incident on it. Either of the reflecting targets can be stationary or moving objects. In Fig.12 the radar is at the point labeled "1." A reflector is a point "2" and real targets are at the points labeled "3." Due to reflections from the reflector to the targets, ghost echoes will appear at the points labeled "4." The appearance of the ghost on the PPI is one possible explanation for perplexing unidentified target motions. If one of the two reflectors is an aircraft and undertakes any maneuvers, the path followed by the ghost is especially erratic. As viewed on a PPI scope perhaps it first recedes from, then "flies" parallel to, and finally overtakes or appears to collide or pass the real aircraft.

Fig. 13 (adapted from Levine 1960) shows the outline of a conventional aircraft surveillance radar PPI (included within the circle). The solid line (A) shows the return echo path of an aircraft traveling at 300 knots. The dashed line (B) shows the echo path that will also result when sufficient radar energy is scattered from the aircraft to a prominent ground reflector located at C, and then reflected back to the aircraft and then to the receiver. In this example, the aircraft is the first of the reflectors, so that the phantom echo always occurs

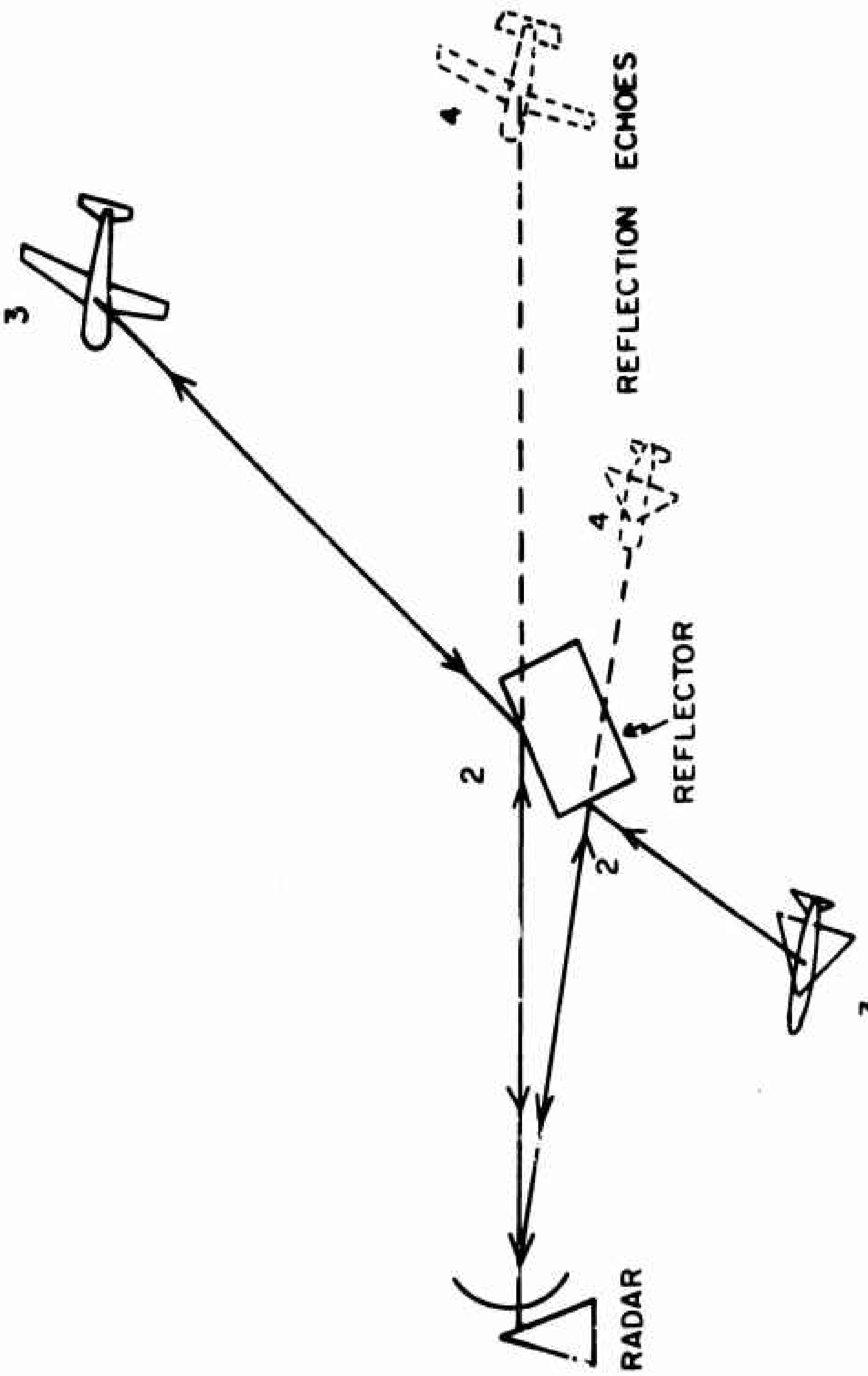


FIG. 12 GEOMETRY OF REFLECTION ECHOES

at the same azimuthal bearing as the aircraft, while its range always exceeds that of the aircraft. Consequently, on the PPI, the path of this ghost always lies outside the aircraft path. However, if the aircraft overflies the ground object, the phantom echo and the aircraft echo will almost merge. In addition, as the apparent range of the phantom is greater with the same radial speed as the aircraft, the apparent velocity of the ghost will be magnified by the ratio of the aircraft-to-phantom distance from the radar. The phantom can appear to exceed 2,000 knots in this manner. In Fig.13 the ghost is moving at 900 knots along a portion of the ghost track.

Fig.13 and the discussion above relate to the case when the aircraft is the first of two reflectors. For the conditions with the ground object as the first of the two reflectors, the phantom echo always occurs at the same azimuth bearing as the ground object. For example, in Fig.14 (also adapted from Levine, 1960) the solid line (A) applies to scattering from the first reflector to the aircraft and back to the receiver. The inward and outward excursions of this path actually occur along a single radial line from the radar site through the first reflector.

In any actual situation, only fractional portions of the ghost echo paths might be of sufficient signal strength to appear on the display. Those particular returns that are closest to the ground object or where the reflector has the most favorable reflecting properties will most likely be displayed. In a radar detecting only moving targets, a stationary ground object might not appear as a target on the scope. Thus, in this manner, the operator's ability to correlate ghosts to a reflecting surface is considerably reduced, especially when many known targets are on the display. From Figs.13 and 14, it is shown that the phantom echo fell outside the display and then returned during a later portion of the flight. Thus, if only portions of the phantom track are a detectable signal, and if (this would usually be the case) there are several targets on the display at once, the operator would find

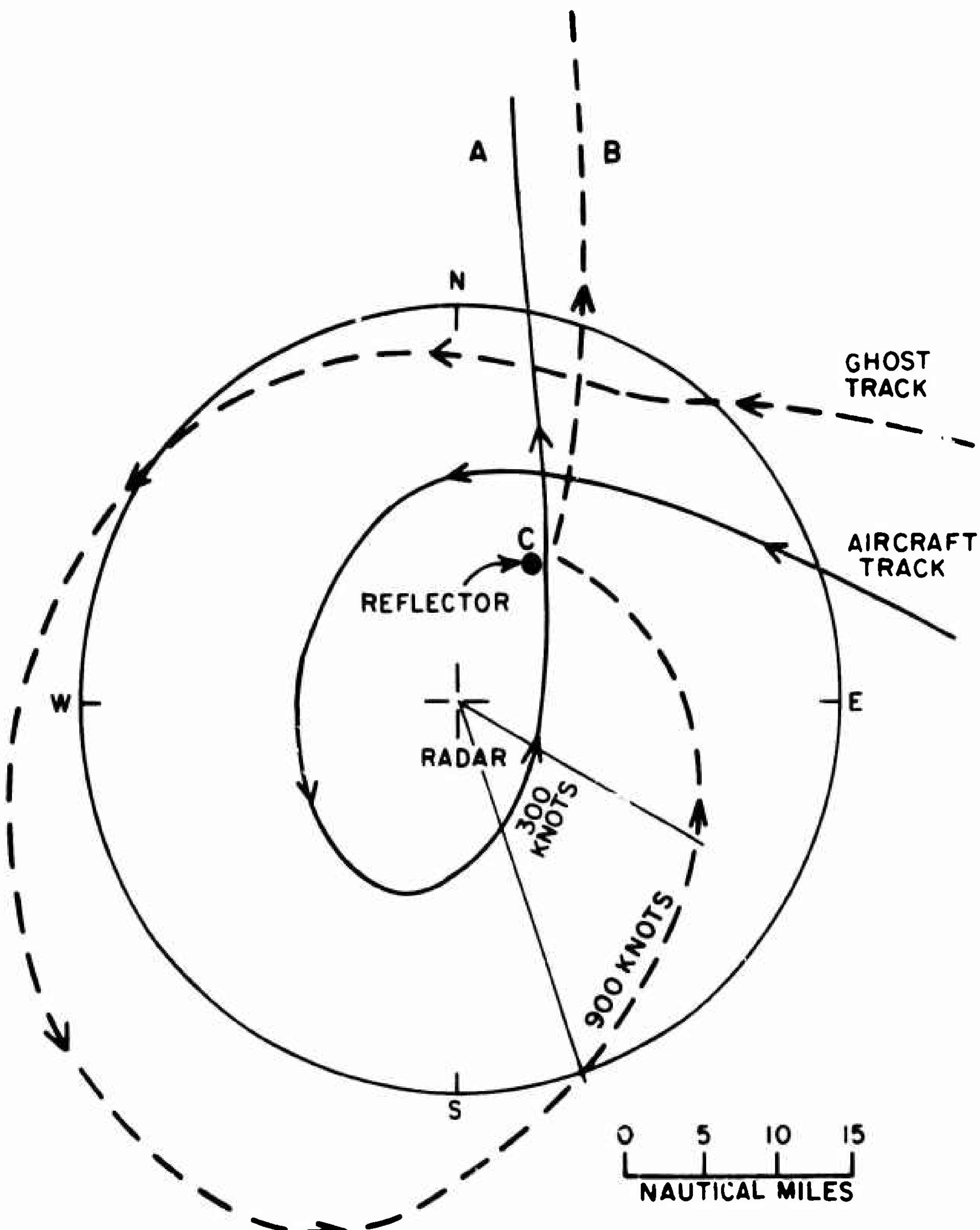


FIG. 13 TRACK OF GHOST ECHO CAUSED BY REFLECTION FROM AIRCRAFT TO GROUND REFLECTOR

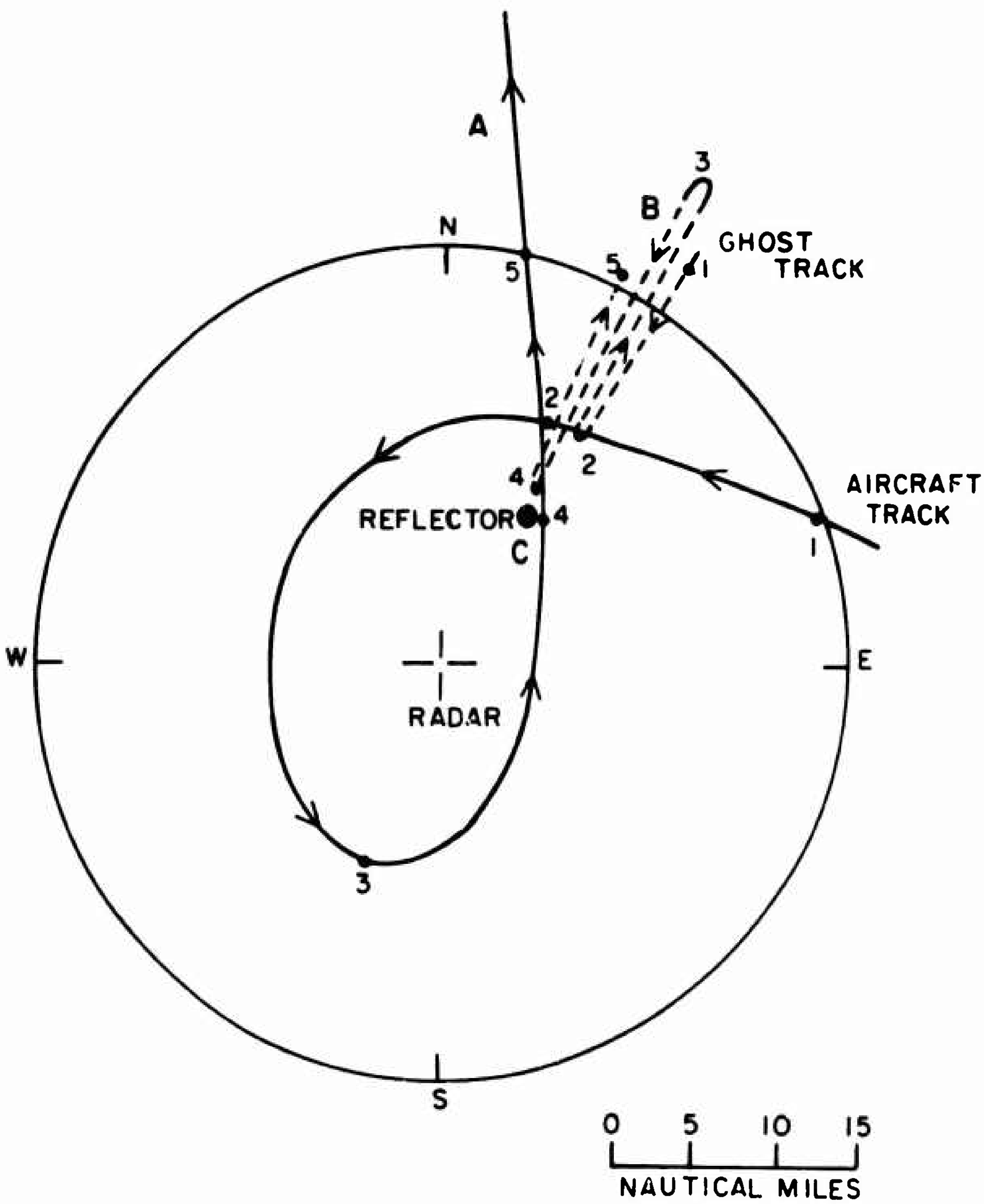


FIG. 14 TRACK OF GHOST ECHO CAUSED BY REFLECTION FROM GROUND REFLECTOR TO AIRCRAFT

it very difficult to discern whether the phantom was real or ghost. He is concerned about the erratic behavior of a target, but he is most concerned by the potential and displayed near-misses to known targets.

In general doubly reflecting ground targets must be of sufficient size and have good radar-reflecting properties to serve as radar-reflectors. Reflectors can be moving or stationary. Reflectors that fit this description include sloping terrain, sloping metal roofs, metal buildings, nearby ground structures, or large trucks and trailers.

Fig. 13 illustrates the possible sporadic nature of reflection echoes. Plate 68a, taken when stratiform precipitation was occurring, documents the fact that there is a sector to the east that is blocked by some object. Plate 68b shows normal ground clutter plus a few probable aircraft. Plate 68c shows the appearance of the PPI when anomalous propagation was causing more extensive ground clutter. In this photograph there is an echo in the sector in which precipitation could not be detected. This ghost echo was found to be produced by reflection from the object causing the blocking to a ground target in the opposite direction. Plate 68d shows the geometry of the situation. The line labeled "orientation of reflector" was found by folding a large tracing of the ground target and ghost echo. When folded along this line, there was near perfect correspondence between the two.

More complex reflection occurrences require a rare combination of reflector/target radar geometry and reflectivities. Analysis indicates that they occur occasionally. However, unless accurate data are recorded at the time of the event, ray tracing techniques will be almost impossible to use in order to reconstruct the possible circumstances. In addition to phantoms, caused by reflecting objects, other types of spurious target returns can be occurring at the same time, further increasing the difficulty of analyzing the unusual sighting. Such things

as extraordinary meteorolcgical conditions, and multiple-time-around echoes can also be contributing effects, making the analysis that much more difficult. When interference problems, operator interpretation, and equipment reliability factors are included, one begins to realize that the explanation of reported unusual observations requires extensive research for each incident, and such research is not possible unless all pertinent information has been documented in detail.

7. Evaluation of Radar Echoes to Identify Targets

When there is an echo on the PPI of a search radar, the operator must determine the nature of the target. The information he has is relative signal intensity, some knowledge of fluctuation in intensity, position, velocity, and behavior relative to other targets. In addition he may be able to infer altitude if he is able to elevate the beam and reduce the gain to find an angle of maximum signal intensity. Previous sections of this chapter have briefly described a number of targets that search radars are capable of detecting. From the discussion it is apparent that there is overlap in the characteristics of different types of targets. Signal intensities, for example, range over several orders of magnitude. Wind-borne and powered targets may have comparable ground speeds depending on the wind speed. Many different types of targets show echo fluctuations. Thus there is no specific set of characteristics that will permit a given echo to be unambiguously identified as a specific target. At best all one can do is say that a given echo *probably* is, or is not, a specific target based on some of the observed characteristics.

Target Velocity

Determination of the direction and speed of an echo in the PPI of a search radar requires some assumptions. A long range search radar antenna generally rotates at about 4 - 8 rpm. At 6 rpm, an antenna rotates through 360° in 10 sec. (=36°/sec). If the horizontal beamwidth of the antenna is 3.6° a point target will be within the beam

for 0.1 sec. as the beam sweeps past. Then 9.9 sec. elapse until the beam again sweeps the target. If on this next revolution there is an echo in the general vicinity of the target detected on the previous sweep the operator must decide whether this echo is from the same target that was detected previously or is from a new target. If he assumes the two echoes are from the same target, he can then compute a velocity. If his assumption was correct, if his computations are accurate, and if the target is at the indicated locations, the computed ground speed is correct. If, however, the two echoes are not from the same target or are from a target that is not at the indicated location, then the computed speed will have no meaning.

The speed computed from the displacement of the echoes from a target at the indicated location represents the ground speed of the target. To aid in the identification of slow moving targets, it is necessary to determine its airspeed. This requires knowledge of the wind velocity at the location including altitude and time of the detection, and the assumption that the target is in essentially level flight. It is often difficult to determine precisely the wind velocity at a given point due to the wide spacing of stations that measure winds aloft and the six-hour interval between observations. Except in complex situations, it is usually possible, however, to extrapolate measured winds for a given location with sufficient accuracy to determine whether the target velocity and wind velocity have sufficient similarity to justify a conclusion that the target is probably windborne. Conversely if there is a large disparity between wind velocity and target velocity a logical conclusion would be that the target could not be windborne.

When an echo that has been moving in an orderly manner on the PPI suddenly disappears, the information for computing its speed also disappears. Any attempts to guess the speed would require the operator to make specific assumptions of the reason for the disappearance. He might assume that the target moved out of range during the brief time

required for one antenna revolution. Such an assumption would probably require a very high speed target. Or the operator might assume that the target decreased altitude to a position below the radar horizon. If the target was located close to the radar horizon, an altitude change of a few tens of feet would be sufficient for it to disappear and the required speed (vertical velocity) would be quite small.

Target Intensity and Fluctuations

The power received from a point target is directly proportional to the radar scattering cross-section of the target and inversely proportional to the fourth power of the distance from the radar to the target. Therefore, for an equal signal to be received from two targets, a target 10 mi. from the radar would have to have a radar cross-section 10,000 times as large as a target at 1 mi. Examples of targets with differences in cross-sections of this order of magnitude are birds with cross-sections of 0.01 m^2 or less and aircraft with cross-sections of up to 100 m^2. Intensity differences such as these can be measured (by gain reduction to threshold of detection), but the nature of display systems such as PPI's is such that differences are considerably reduced. An echo on the PPI is composed of many small dots that result from an electron beam that excites the coating on the face of the tube causing it to emit light. The coating may be designed to emit light only when the electron beam excites it or may continue to emit light for some time after the excitation has ceased (persistence). The latter is usually the case for PPI's where the operator depends on persistence to see the 360° coverage provided by the rotating antenna. Haworth (1948) states that from 150 - 200 spots can be resolved along the radius of magnetically deflected radar tubes. Gunn (1963) points out that since the PPI trace lines converge at the center the light output per unit area of the tube face will decrease with increasing radial distance from the center. As a result echoes near the center are 'painted' with a higher intensity than echoes of comparable strength anywhere else on the display. These characteristics of the display system act to conceal further the relative magnitudes

of the signal intensity of targets at different ranges, so that the operator loses much of the available radar information when it is displayed on the PPI. Fluctuations are smoothed out, and the intensities are normalized to some extent. The result is that he can give some information on an unknown target in comparison with a known target *at the same range*. Positive knowledge of the nature of a target at a given range can only result from auxilliary data. For example, if the operator is in contact with an aircraft that is over a given point and he has an echo at that point he will logically assume the echo is from the aircraft if the echo is moving on the course and at the speed reported by the pilot. He could then compare the intensity and fluctuations of other targets at that range with those of the known target and draw some conclusions as to whether they might be larger or smaller than the aircraft.

Behavior Relative To Other Targets

Very little can be said about a target from the examination of a single echo but some information can be obtained by comparing the echo with other echoes on the remainder of the PPI. When the echo is interpreted in terms of the appearance and behavior of other echoes a logical explanation may become evident.

For example, the author has seen isolated targets on the PPI that were moving toward the radar in a direction opposite to that of the wind, so that it was obvious that they could not be windborne. A slight elevation of the antenna caused them to disappear so it was apparent that they were at low levels. No attempt was made to send aircraft to the vicinity to look for targets. All other attempts to interpret the nature of real targets on that half of the PPI that would return the displayed echoes were futile. When the remainder of the PPI was examined it was found that the speed of a line of thunderstorms moving toward the station was the same as that of the echoes to the east. The direction of movement, however, was the same as that of the wind and not opposite, as with the echoes to the east. Further, the distance to the thunderstorms to the west was the same as the distance to the unknown echoes to the east. With this additional information it seemed likely that the echoes to the east were reflections

of portions of the thunderstorms to the west. The obstacles causing the reflections were subsequently identified as large nearby chimneys that extended only slightly higher than the height of the radar so that when the antenna was elevated slightly the chimneys were below the main beam and no longer caused reflections.

Since the reflectors (chimneys) were very narrow, the reflection echoes were very narrow but their length was equal to the diameter of the precipitation area. The echoes therefore had a long, narrow (cigar-shaped) appearance. Since the apparent lengths in some cases were 10 - 15 mi. they were not mistaken for some type of flying vehicle.

Although the solution of the case discussed here is a simple, and, on the surface, obvious one, it does demonstrate the necessity of studying the entire PPI, not just one or two odd echoes. The case also illustrates how echo characteristics become distorted when the return is from a target not at the indicated location. The long, narrow shapes of the reflection echoes, a vertical extent of only 1° - 2° at ranges less than 50 mi., and movement against the wind all tended to rule out precipitation as the target.

The problem of identifying reflections is very difficult. The simplest case is where the reflector and reflected target are both fixed. The reflected echo is always in the same position and whether it appears or not depends on propagation conditions and if the reflector is of limited vertical extent on antenna elevation angle.

When the reflector is fixed and the target is moving the reflected echo also moves but in a different direction than the true target. Still the geometry is relatively simple and the reflected echo will move toward or away from the radar along a radial line extending from the radar across the reflector. The reflected echo will appear to move toward the radar when the distance from the radar to the true target is decreasing and away from the radar when the distance from the radar to the true target is increasing. The apparent speed of the reflected echo toward or away from the radar corresponds to the speed

of the true target toward or away from the reflector. This is *not its actual ground speed.* A target could move at 500 knots along a constant-distance circle from the reflector, yet the reflected echo would be stationary. Only if the target moved directly toward or away from the reflector would the reflected echo have the same speed as the target; but the speed of the reflected echo can never exceed that of the target.

When the reflector is moving and the target is stationary (see discussion of Fig.13) the reflected echo track is always further from the radar than the reflector track. The reflection echo will follow roughly the same track as the reflector but its apparent speed may be much greater depending on the distance between the reflector and target. When the reflector is far from the target the apparent speed of the reflected echo will be much greater than the true speed of the reflector. When the reflector is very close to the target the reflected echo will be close to the position of the reflector and its apparent speed will be comparable to that of the reflector.

The situation where both the reflector and the target are moving is very complex. The apparent speed of the reflected echo will depend on the relative speeds of both reflector and target. When the reflector is moving slowly, the condition of a stationary reflector will be approached but not quite realized. That is, the reflected echo will have a maximum apparent speed that does not greatly exceed that of the target, but since the reflector is moving, the reflection echo will not be restricted to motion along a single radial line.

When the reflector is moving rapidly compared to the target, the result is similar to the case of a fixed target, that is the reflected echo track approximates the reflector track but its apparent speed will be greater. When the target moves, the track correspondence is not as good and the reflected echo's apparent speed may greatly exceed that of the reflector.

The most complex cases are those in which a moving reflector is not illuminating a single target but may show a different target on each scan of the radar. In these cases there is no correspondence between reflected echo track and reflector track. Speed computations in these cases are erroneously based on multiple targets. Attempts to compute a speed therefore produce values that can vary from some very low speeds to thousands of knots.

It is obvious from the preceding discussion that it is nearly impossible to identify an unknown target working in real time at the PPI. To establish that an unknown is a reflection echo requires a determination of whether it is at the same azimuth as a reflector. Since any one of many other echoes could be the possible reflector, the geometry would have to be applied to each one in turn. When numerous echoes are on the PPI this is impossible.

Much valuable information can be recorded for later detailed study by photographing the PPI with a radarscope camera during each revolution of the radar antenna. Later the films can be studied, either as time-lapse motion pictures or frame by frame. For many ye[illegible] type of radarscope photography has been used for studies of [illegible]r-detected precipitation patterns and has provided insights into m[illegible]orological phenomena that would have been impossible from subjective verbal descriptions of the echo patterns.

Radarscope photographs of the PPI have all the limitations of the PPI presentation itself. They cannot show intensity differences or minor intensity fluctuations. They do have the powerful advantage of making it possible to review a puzzling echo hundreds of times at various rates of viewing and to study the appearance and behavior of *all* echoes before, during, and after the episode. Only by the study of radarscope films and many other supporting data is it possible to arrive at even a tentative conclusion that a given echo cannot be explained.

8. Conclusions

Radar is a valuable instrument for detecting and ranging targets that are not visible to an observer due to darkness, extreme distance, intervening rain, cloud cover, haze, or smog. Radar can also detect, or reflect from, atmospheric discontinuities that are not visible to the eye. The echoes of real targets and apparent targets that result from RFI, reflections, or system noise may on occasion produce scope presentations that are extremely difficult or impossible to interpret. The major difficulty is that while radar is designed to beam radiation in a specific direction and detect targets within a specific distance, it does not always do so. The transmitted radiation, while concentrated in a main beam, goes out as well, in many other directions. Portions of the main beam and the lobes may be reflected in other directions by nearby objects, by solid targets a considerable distance from the radar, or by layers or small volumes of atmospheric inhomogeneities. All of this radiation in various directions is refracted by atmospheric temperature and moisture profiles to deviate further from its original path. Portions of this radiation that impinge upon any of a wide variety of targets are reflected back along a reciprocal path and presented on the PPI as if they were at the position determined by the antenna elevation and azimuth, and the time required for the most recently transmitted pulse to travel out and back. Some of the displayed echoes will represent targets at the indicated locations. Some of the displayed echoes will be from targets not at the indicated position, and some of the echoes will not represent targets at all, but will be due to system noise or RFI. Since radar does not differentiate between the unique characteristics of different types of targets, it is impossible for even the most experienced radar operator to look at the PPI and positively identify all echoes on the scope.

Some auxiliary information on the possible nature of the targets may be derived from the study of the appearance of the PPI on successive antenna revolutions or from a series of PPI photographs. These successive

presentations show the interpreter apparent motion and changes in intensity. This additional information is useful but still does not permit positive identification of the target. Only such generalizations may be made as that the target appears to be moving at 250 knots so it cannot be precipitation, birds, or a balloon. To even make this generalization the operator has to know or make some assumptions about the probable wind speed in the vicinity of the apparent target.

The data presented on the PPI of a single radar, therefore, do not permit the operator to say very much about the possible nature of a target displayed as an echo on the PPI. Many additional data are required such as meteorological conditions between the radar and the apparent location of the target, and auxiliary radar information such as target elevation angle and the bearing of the target from another radar. The detection of a target at the same location by two or more radars with different characteristics would usually rule out multiple trip echoes, reflections, and detection by side lobes. Surveillance by more than one radar would also aid in establishing continuity along an echo track if the rotation rate of the two radars was such that they were 180° apart so that one would "see" the echo when the other was "looking" 180° from it. The problem of determining speed is based on the assumption that a single target has moved a specific distance during the time that the beam is not aimed at it. In many cases this may be an erroneous assumption, and it requires either continuous tracking or surveillance by numerous radars to determine whether only a single target is involved.

It is hoped that this discussion of radar has convinced the reader that radar data are only a tool to be used in conjunction with many other bits of information for the solution of various problems. Radar alone cannot specify the exact nature of all targets especially when it was probably specifically designed to detect specific target types. It can only provide the operator with some generalized information about the target and he can only draw some general conclusions based on a number of assumptions he must make. If he makes the wrong assumption,

he will come to an erroneous conclusion.

This does not mean that radar could not be a useful tool in any further studies of the UFO problem; it simply points out the need for, and problems of, gathering photographic and other data from a number of different types of radar on specific incidents before the data could be carefully analyzed and interpreted with any degree of confidence.

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Chapter 6
Sonic Boom

William Blumen

1. Introduction

Observers of unidentified flying objects report a variety of sound effects associated with the phenomenon. Some report sharp, explosive sound during rapid acceleration or high-speed flight. Others refer to humming, whining or whirring noise while the UFO is hovering or moving at relatively slow speeds (Hall, 1964). Still others mention whistling or swishing sounds suggestive of rushing air.

More remarkable than any of the foregoing, however, are reports that describe the UFO as moving at velocities far in excess of the maximum speed of sound in the earth's atmosphere without producing any noise or shock wave that would normally be expected under such conditions of atmospheric displacement. No characteristic "boom" is heard in these instances.

The absence of a sonic boom in these cases remains a mystery. Possible explanations are that: a) actual speed was overestimated; b) a natural atmospheric effect that could suppress the sonic boom was present; or c) the object or phenomenon did not displace the atmospheric gases through which it was passing at supersonic speeds.

In this chapter we shall present the basic concepts involved in the production of the sonic boom or shock wave resulting from the passage of an object through the atmosphere at speeds greater than that of sound at the altitude of flight. Natural effects that are theoretically capable of rendering such shock waves inaudible at ground level will also be discussed, as will current research aimed at suppression of sonic booms by aircraft design modification and other means.

In general, it would be unrewarding to analyze each UFO report in conjunction with meteorological data to determine if a sonic boom from a particular object flying at supersonic speed would be heard at ground level. The difficulties are two-fold: first, the existing state of knowledge concerning meteorological effects on sonic booms is sufficient only to provide information in terms of statistical probabilities (Roberts, 1967); and second, local meteorological

features which occur between weather observing stations and/or which occur between the times of scheduled observations would not be observed.

2. Sonic Boom Generation

Sound waves are a manifestation of the compressibility of air. A source capable of compressing air produces pressure fluctuations, called sound or compression waves, which travel through the atmosphere. The peaks and troughs of the waves correspond to maxima and minima of the pressure fluctuations. The leading edge of the wave or wave front is approximately spherical in shape, and the pressure disturbance propagates away from the source in a series of concentric spheres. The speed of propagation of these waves, the sound speed, varies with the temperature and pressure of the air through which the waves travel. The maximum value for speed of sound waves is generally at ground level and reaches about 760 mph. The sound speed may show considerable variation in the atmosphere, alternately decreasing and increasing with altitude. A minimum value of 580 mph is reached at approximately 50 miles above the earth's surface. However, these values are principally a function of altitude, but they also vary with the time of day, season and latitude and longitude. The following are approximate average values:

Height (feet)	Speed of Sound (miles per hour)
0	760
10,000	735
20,000	707
30,000	679

Pressure disturbances are generated whenever a body, such as an airplane, moves through the atmosphere and displaces the air around it. In subsonic flight the speed of the aircraft is less than the local sound speed and the wave disturbances propagate away from the plane in all directions. These pressure variations are generally weak and too slowly varying to be detected by the ear (Carlson, 1966).

An aircraft travelling at supersonic speeds moves faster than the pressure disturbance it generates. When this occurs the plane is always ahead of the wave front and the spherical waves emitted at successive points along the flight path become tangent to lines sloping backward from the bow of the plane. These lines form a cone, the surface of which is the shock wave. Shock waves are formed by each protuberance on the plane's exterior. However, with distance, the various shock fronts tend to coalesce into two large shock fronts, usually attributed to the bow and to the tail of the plane. Fig. 1a shows how the fronts intersect level ground from a hypothetical flight path parallel to the ground surface at constant sound speed and with no wind. The indicated abrupt pressure rise and fall is responsible for the sonic booms heard at the earth's surface. Two booms will be heard as the "bow" and "tail" shocks successively pass over an observer but the ear may not always register the separate shocks when they are of different intensities (Carlson, 1966) or when the observer is taken by surprise.

The ratio of aircraft speed to the sound speed at its altitude is called the Mach number. The limiting value at which no sonic boom is heard, because of atmospheric effects, is called the cutoff Mach number (Wilson, 1962). Studies made by Wilson (1962), Kane (1966) and Roberts (1967) have established that the cutoff Mach number ranges roughly between about 1.0 and 1.3 depending on atmospheric conditions and the altitude of the plane. This means that sonic booms produced by objects moving faster than 1.3 times the sound speed should be heard at ground level.

The angle between the shock front and the ground becomes smaller as the aircraft speed increases relative to the sound speed. In this situation the sonic boom may not be heard at ground level until the plane has passed from view. Wilson (1962) has estimated that the plane may be as much as 25 miles away from the point on the ground where the sonic boom is heard.

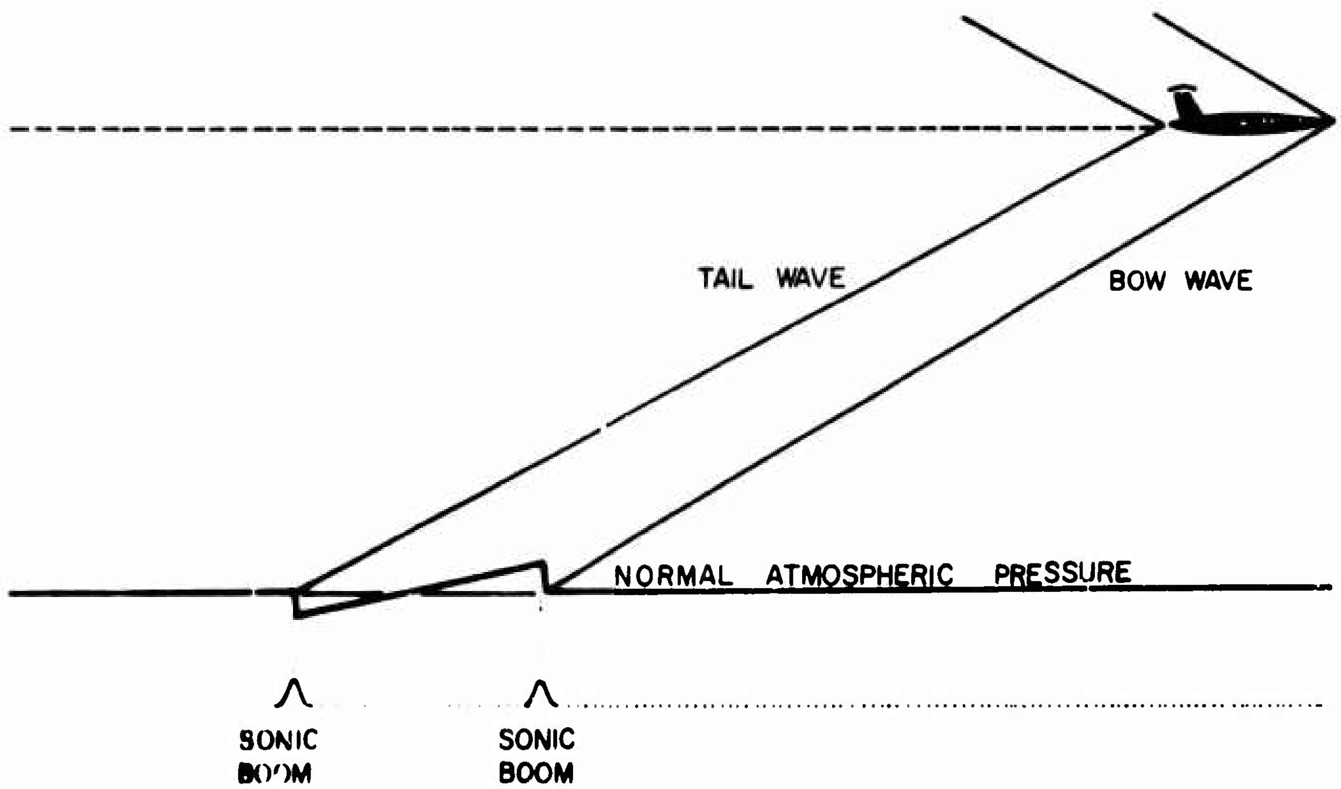

Fig. 1a

SHOCK WAVES created by the passage through the air of a supersonic airplane coalesce into two large cone-shaped shock fronts, shown here in cross section, that are carried along with the airplane. Each front is a region of compressed air that creates a distinct "pressure jump" at the ground. The changes in atmospheric pressure are heard by an observer as two sonic booms in succession.

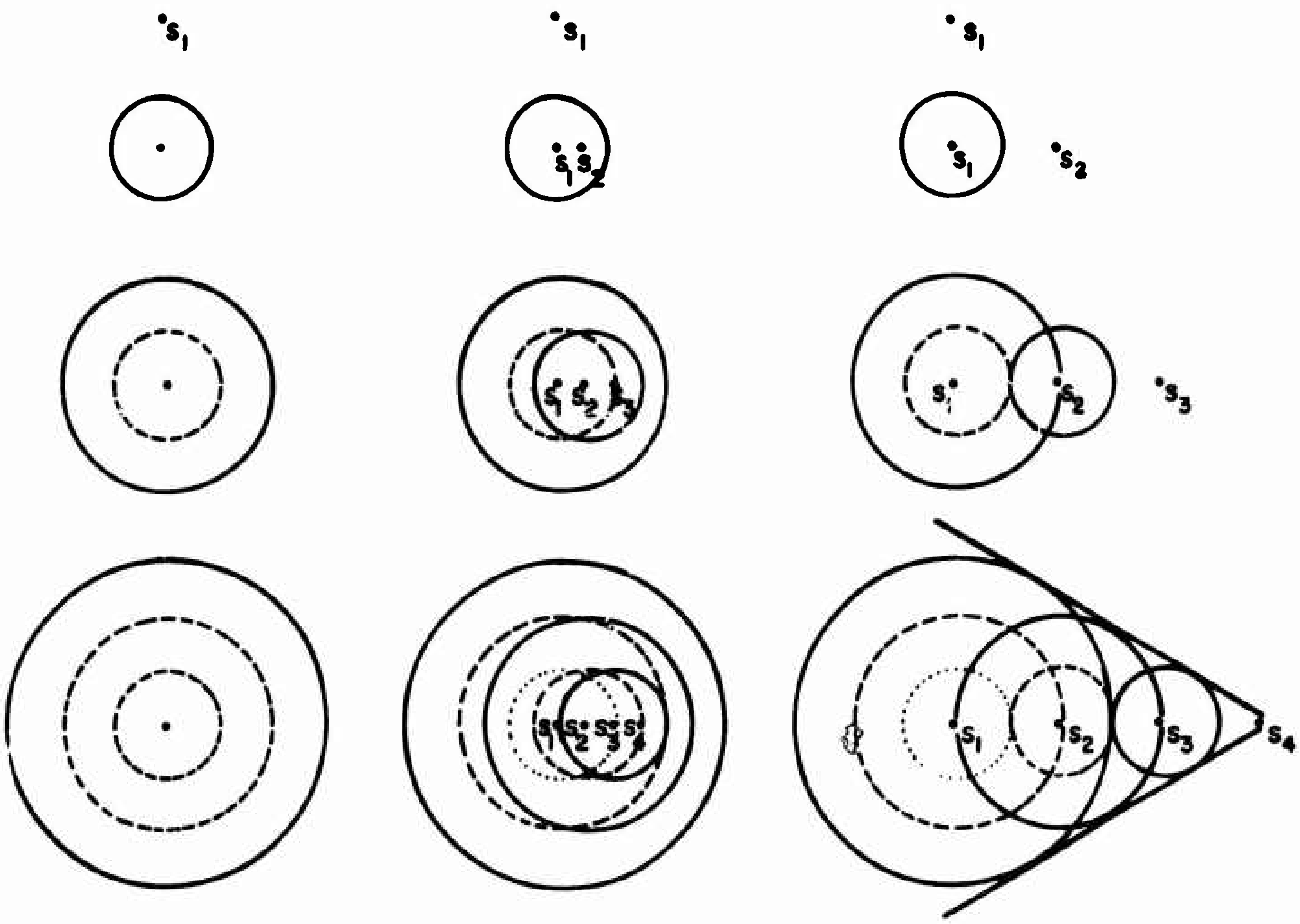

Fig. 1b

SONIC BOOM arises because a supersonic airplane moves faster than the pressure disturbances, or sound waves, it propagates. A stationary source *(left)* emits spherical sound waves that move outward like concentric ripples. If the source moves at less than the speed of sound *(middle)*, waves emitted at successive positions are crowded in the direction of movement; they overtake the moving source and "warn" the air of its approach. But disturbances from the earlier emissions of a supersonic source *(right)* cannot overtake the source, which arrives without warning and creates a shock wave. The spheres become tangent to the sides of the shock wave cone.

3. Atmospheric Effects on Sonic Boom Propagation

When the actual wind and temperature variations that occur in the atmosphere are taken into account, the simple conical pattern of the shock front may become quite distorted. The sound speed generally decreases with altitude between the ground and the plane. Therefore, as a propagating shock wave descends toward the ground, the portion of the wave front closest to the earth moves faster than the portions above. If the sound speed decreases sufficiently rapidly with altitude, the wave front may become perdendicular to the ground. In this situation the shock never reaches the ground because it begins to travel parallel to the ground before it gets there (Carson, 1966). Physical requirements for such an effect, however, are unlikely, even under extremely abnormal atmospheric conditions. In any event, an object moving through the atmosphere at any altitude parallel to the earth's surface, at a speed greater than the speed of sound at ground level would inevitably produce a sonic boom.

The decrease of sound speed with altitude also affects the portion of the wave front that spreads out to the sides of the plane. An investigation of the effect by Kane (1966), under conditions of no wind, shows that the lateral extent of the sonic boom at ground level ranges from about 10 to 35 miles on either side of the ground track of the plane. Furthermore, the intensity of the shock wave will be diminished as it spreads out. Consequently the boom will become less intense on either side of the flight track.

When wind is present, the wave front progresses at a rate which is the sum of the sound speed and the wind speed. Therefore the effect on the wave front by the temperature decrease is counteracted if a tail wind increases with altitude. If a tail wind decreases with altitude the distortion of the wave front caused by the temperature variation is reinforced, while a head wind produces the opposite effect. The situation becomes more complicated when the horizontal variations of wind and temperature are considered.

Other atmospheric features could produce unusual sonic boom patterns at the ground. Among these are: turbulent air motions in the lowest few thousand feet of the atmosphere, the type of clouds present and their spatial distribution, and temperature inversions. None of these meteorological phenomena have been studied in sufficient detail to produce conclusive results about their effects on sonic booms. However preliminary investigations have been reported (Roberts, 1967).

4. Design Modifications and Maneuvers

Although various government agencies, industrial organizations and university research projects are currently engaged in seeking methods to reduce sonic boom intensities, all known practical supersonic airplane designs will produce sonic booms (National Academy of Sciences, 1967). Furthermore, according to the Academy report, "The possibility that unconventional configurations may be devised which will yield significant reductions cannot be disallowed but, at present, the future must be viewed in terms of small reductions obtained through better understanding of theory, design refinements of conventional aircraft and improvements in propulsive efficiency and operating procedures." Research efforts are continuing in an effort to find an unconventional design, with practical aerodynamic characteristics, which would minimize or eliminate the sonic boom.

The various research efforts to suppress sonic boom intensities which are under investigation are reviewed below.

The pressure distribution at ground level, shown in Fig. 1a and 1b is the so-called "farfield" signature. The shock fronts emanating from protuberances on the aircraft have little effect on the pressure pulse at ground level. The sonic boom can be reduced, but not necessarily eliminated, if the aircraft climbs at subsonic speeds before making the transition to supersonic speeds at high-altitude cruising levels. Optimization of the arrangement of the various components, such as the shape and position of the wings, may lessen sonic boom intensity. Long, slender and blended configurations appear to offer

the best compromise between maximum aerodynamic performance and low sonic boom levels. Reduction of the peak pressures at ground level by design modifications is also being attempted. For example, a "stretched" design would alter the point at which the various waves form a bow and tail shock. With this type of design a less rapid rate of pressure rise would be produced at ground level and consequently a less audible boom would result (McLean, 1966; NAS, 1967).

Aircraft accelerations and maneuvers at various altitudes cause sonic booms of varying intensities in localize regions at or above ground level. It is possible, during common flight maneuvers, to produce local pressure buildups which may be more than twice as large as those produced by the same aircraft in level, unaccelerated flight. The subsequent "superbooms" occur at isolated points at ground level in contrast to the ordinary booms that move with the aircraft. Limitations on rapid accelerations and maneuvers would reduce the intensity and frequenty of "superbooms" but could not be expected to suppress sonic booms altogether (Maglieri, 1966).

In subsonic flight, pressure disturbances propagate ahead of the aircraft altering the airstream in such a way that abrupt pressure changes do not occur. In supersonic flight however, pressure distrubances cannot propagate ahead. In order to prevent the buildup of a shock wave in supersonic flight, the Northrup Corporation is currently working on a method to modify the airstream through an electromagnetic force field concentrated at the nose of the aircraft. This work is still in preliminary stages and experiments have only been undertaken in wind tunnels (Aviation Week and Space Technology, 1968).

5. Comments

Although sonic boom research has progressed rapidly since the early 1950's, the complete suppression of sonic booms at ground level by means of present technology does not appear imminent. This does

not mean that sonic booms are always heard in conjunction with supersonic flight. Some meteorological factors occasionally could reduce sonic boom intensities or, even more rarely, prevent sonic booms from reaching the ground at all. However, the reported total absence of sonic booms from UFOs in supersonic flight and undergoing rapid accelerations or intricate maneuvers, particularly near the earth's surface, cannot be explained on the basis of current knowledge. On the contrary, intense sonic booms are expected under such conditions.

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Chapter 7

Atmospheric Electricity and Plasma Interpretations of UFOs

Martin D. Altschuler

Research into atmospheric electricity is important and difficult. Although many aspects are now becoming clear, much remains controversial or unknown. Even common events, such as the thunderstorm and the lightning flash, continue to provide fascinating challenges to science.

Electric fields are produced by clouds, fog, rain, sleet, snow, tornadoes, dust devils, volcanos, earthquakes, meteors, and contaminants in air. On mountains, electrical activity often becomes intense. Experienced climbers can tell bizarre stories of mountaintop electricity. Researchers themselves have often been astonished at nature's complexity. Ball lightning, for example, although witnessed and reported many times in the past, has only with difficulty been established as a genuine scientific problem. Years of patient effort were required to distinguish ball lightning from retinal after-images and optical illusions. In view of the numerous manifestations of atmospheric electricity, it is reasonable to try to determine whether or not some luminescent UFOs are indicative of yet another electrical phenomenon of nature.

Much research has been done theoretically, in the laboratory, and in the field that bears on the problems of atmospheric electricity and the plasma state of matter. Here we emphasize the more unusual (and often speculative) aspects of these subjects and their possible correlation with descriptions of UFO behavior. People who have witnessed unusual electrical phenomena of the types reviewed

in this chapter are invited to send reports to

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1. Definition of a Plasma

In its lowest energy state, an atom contains an equal number of electrons and protons, and is electrically neutral. By gaining or losing electrons, an atom or molecule can acquire an electric charge. A charged atom or molecule is called an ion. If some of the atoms of a gas become ions, the gas is said to be partially-ionized. When there are enough ions or electrons to affect the physical properties of the gas, the gas is called a plasma. The "plasma state of matter" refers to an ionized medium.

An atom may become ionized by (a) absorbing a quantum of high energy electromagnetic radiation, (b) colliding with a fast particle (atom, ion, or electron), (c) capturing an electron. In processes (a) and (b), atoms lose one or more electrons and become positive ions. In process (c), atoms gain an electron and become negative ions. The ionization of the outermost layers of the atmosphere (above 65 km) is caused primarily by the absorption of solar ultraviolet radiation and x-radiation (process (a)). The weak ionization in the lower atmosphere is largely an effect of cosmic ray particles (mostly fast protons)

(process (b)). Free electrons in the lower atmosphere are quickly captured by oxygen molecules, which then become negative ions (process (c)).

When large electric fields are present, electrons and ions are accelerated to high velocities in short distances, and may acquire enough kinetic energy to ionize neutral atoms upon collision. The new charges are accelerated in turn by the electric field, collide with still other neutral atoms, and produce more electrons and ions. The ionization of a neutral gas by the acceleration of a few electrons and ions in a large electric field is called an avalanche process. The avalanche process is responsible for coronal point discharge (St. Elmo's fire), lightning flashes, neon and fluorescent lighting, and Geiger counters.

Since electrons can be accelerated by high-frequency electric fields, ionization is sometimes possible in the presence of microwaves. High temperature shock waves surrounding meteors and re-entering space vehicles also cause ionization in the atmosphere.

When a free electron and a positive ion collide, the electron may be captured. When a negative and a positive ion collide, an electron may be transferred from the negative to the positive ion. In such collisions, called recombination processes, ions are neutralized and become atoms or molecules. In the lower atmosphere, plasma (such as that created in a lightning flash) is rapidly neutralized through such processes. Radiation may be emitted during recombination.

2. Occurrence of Plasma

Probably 99% of all the matter in the universe is in the plasma state. Within the stars, hydrogen, helium, and the other abundant atoms are completely ionized.

The visible surface of the sun, called the photosphere, is host to a mysterious plasma phenomenon, the sunspot. The strong

magnetic fields which emanate from sunspots interact with the plasma of the outer solar atmosphere. As a consequence, violent events, known as solar flares, are often generated in regions where the magnetic field gradient is large. During a solar flare, ions and electrons are accelerated out of the sun's atmosphere into interplanetary space. Some of these fast charged particles interact with the earth's magnetic environment, and contribute to short-wave radio blackouts, auroras (Northern and Southern Lights), and geomagnetic storms.

Basic plasma research is vital in many technological areas. In the field of communication, problems arise in connection with radio and radar transmission through plasma regions such as the ionosphere and the ionized sheath surrounding re-entering spacecraft. Laboratory efforts are under way to control the reactions of nuclear fusion for power generation. If successful, present experiments may lead to efficient sources of power which do not require fossil fuel or fissionable materials. In the field of space technology, engineers are developing low thrust ion rocket engines to propel the next generation of interplanetary spaceships.

3. Plasma Properties of the Lower Atmosphere

The lower atmosphere (below 60 km) is not a plasma under normal conditions. In every cubic meter of air at sea level, the fair weather atmosphere contains roughly 3×10^{25} electrically neutral molecules and only about 5×10^{8} ions. About 10^{7} ion pairs are created per cubic meter every second by ionizing radiation, and a like number are neutralized by recombination processes. The lifetime of a light ion is several hundred seconds. When dust particles are present, light ions are rapidly absorbed, and long-lived heavy ions are created. Over land at ground level, gamma rays emitted by natural radioactive substances are the primary cause of atmospheric ionization. Above a few hundred meters over land, and everywhere over the oceans, cosmic

ray particles and secondaries are the major source of ionization. In the lower atmosphere (below 60 km) unattached electrons are immediately captured by oxygen molecules.

The presence of even a few ions in the lower atmosphere means that air is not a perfect insulator. An electric charge placed on a metal sphere which is insulated from the ground and suspended in air, will leak into the atmosphere; the higher the altitude of the sphere, the faster will be the leakage of electric charge.

Where air pollution is prevalent, the light ions are collected on heavy dust particles, creating heavy less-mobile ions. The electrical conductivity of polluted air is often ten times less than that of clean air.

The earth's atmosphere may be represented as a leaky dielectric medium bounded by electrically conducting layers (or equipotentials) at sea level and at about 60 km height. Sea level is taken as the zero reference or ground potential. The layer at 60 km, now called the electrosphere, is the lowest level in the atmosphere of uniform electrical potential. This article deals with the electrical effects that are possible in the lower atmosphere, where UFO's are reported.

4. The Fair Weather Electric Field

At sea level in fair weather, there exists an average electric field of about 130 volt/m directed downward. The potential of the electrosphere is about 300,000 volts positive with respect to the earth's surface. The earth's surface contains over its entire area a net negative charge of 5×10^5 coulombs (or 10^{-9} coulomb/m^2). An equal positive charge resides in the atmosphere above the ground. Because air is not a perfect insulator, an electric current of 1800 amp (or 3.6×10^{-12} amp/m^2) flows downward (i.e. positive ions migrate downward, negative ions migrate upward). At higher altitudes, the current remains constant but the electric field decreases as the

electrical conductivity increases. At the height of commercial jet aircraft (12 km), the electrical potential of air has reached 90% of the p tential of the electrosphere (i.e. about 270,000 volts). This indicates that most of the positive charge resides in the troposphere in the form of positive ions.

With the values known for the electrical conductivity of air, the negative charge on the earth's surface should leak away in about five minutes. To maintain the negative charge on the earth's surface, and consequently the electric field of the lower atmosphere, a charging mechanism is needed which acts continuously.

5. Thunderstorms and the Electric Circuit of the Atmosphere

Thunderstorms maintain the fair weather electrostatic field. Every hour, several hundred thousand lightning flashes and coronal point discharges transfer negative charge from the bases of thunderclouds to the ground. The average charge transmitted by a lightning flash is estimated to be about 20 coulombs. Positive ions also rise from the tops of thunderclouds.

Many theories have been proposed to explain how negative and positive charges are separated in a thundercloud. The mechanism must (1) give a positive charge to the upper part of the cloud and a negative charge to the lower part of the cloud,
(2) provide a charge separation rate of several amperes.

It is generally believed that as precipitation particles fall they acquire negative electric charge. Consequently, negative charge is carried to the bottom of the cloud. A detailed understanding of the mechanisms involved in transferring charge between precipitation particles (and air pollutants) is of major scientific importance.

Strong evidence that thunderclouds act as batteries for the atmosphere is provided by the daily fluctuations in the fair weather

electric field. Over the oceans the fair weather electric field fluctuates 15 to 20% about its mean value, and reaches a maximum at 1900 Greenwich Mean Time everywhere over the earth regardless of the local time. Smaller secondary maxima occur at 1500 GMT and at 0700 GMT. Much of the earth's thunderstorm activity occurs in tropical regions during midafternoon when surface heating is most apt to produce strong convection. At 1900 GMT, it is midafternoon in the Amazon basin; at 1500 GMT, it is midafternoon in Africa; at 0700 GMT, it is midafternoon in Indonesia. The minimum fair weather field occurs at 0300 GMT when it is midafternoon in the middle of the Pacific Ocean.

If each thunderstorm supplies a charging current of 1 amp, there must be at least 1800 thunderstorms raging simultaneously over the earth at any one time to maintain the fair weather electric field. This is not an unreasonable estimate. It seems probable, therefore, that thunderstorms are the prime cause of the earth's electrical activity.

6. Properties of Lightning

Current surges in the atmosphere are known as lightning. Lightning limits the magnitude of the electrical dipole of a thundercloud. Only about 20% of all lightning flashes are between cloud and ground. The majority of flashes occur within clouds. Here we briefly describe only the cloud-to-ground event, for which better information is available.

What appears to the eye as a single lightning flash is actually a number of individual charge surges, called strokes, recurring in rapid sucession. A flash consists of between one and forty main strokes, each of which is preceded by a leader stroke. The median number of strokes in a lightning flash is about three.

When electric field strengths build up to values of about 3×10^6 volt/m near the edge of a cloud, avalanche processes become important. The visible lightning event begins with the initiation of a stepped leader from the cloud region where the electric field is most intense. The stepped leaser is aconducting channel, perhaps a few centimeters in diameter, which is at essentially the same potential as the base of the cloud. Consequently, as the leader progresses downward away from the cloud, the electric field (i.e. the potential gradient) between the tip of the leader and the surrounding air continually increases, so that further ionization becomes easier.

After advancing about 20 meters (the exact distance depending on the field strength), the leader pauses for about 50 microseconds, forges ahead another 20 meters, stops again, and so on. (It is believed that the ionization of the air immediately ahead of the stepped leader is initiated by an avalanche region called a pilot streamer.) The stepped leader advances downward toward the ground along a zigzag path roughly parallel to the electric field. After about 100 steps and 50 milliseconds, the stepped leader has almost traversed the 2 km or so between the cloud base and the ground. When the stepped leader descends to about 20 meters altitude, it is met by a positive streamer from the earth. (The potential difference between the cloud and the ground may reach 10^8 or 10^9 volts before a lightning flash).

As soon as the conducting channel between the cloud and the ground is completed, the main (or return) stroke begins. In less than 10 microseconds, a current of about 20,000 amp is forcing its way through a conducting channel only a few millimeters in diameter. (The maximum current ever recorded in a lightning flash was 345,000 amp.) On the average, about 10^9 joules (an energy equivalent to ¼ ton of TNT) are released in the flash event.

The temperature in the lightning channel, measured spectroscopially, reaches 30,000°K only 12 microseconds after the passage of the tip of the return stroke, but decays so rapidly that it falls to 5,000°K in about

50 microseconds. If thermalization is achieved, these temperatures are hot enough to cause considerable dissociation and ionization of air molecules. Some scientists argue, however, that thermal temperatures never exceed a few thousand degrees Kelvin. The precise time variation of the thermal temperature is important in estimating lightning damage by acoustic shocks.

Magnetic field strengths associated with lightning are in the neighborhood of 1 tesla ($=10^4$ gauss), so that the plasma pinch effect is probably of importance. Possible magnetic effects of a lightning stroke have been considered in connection with ball and bead lightning.

After the first leader and return stroke, the lightning flash may continue with another current surge along the same conducting channel. This second stroke is initiated by a dart leader, which advances continuously (not in steps) and more rapidly than the stepped leader. The dart leader follows the main channel to the ground and ignores the ungrounded branch channels of the first stroke. When the dart leader reaches the ground, a return stroke follows.

Recombination processes work rapidly in the atmosphere. Only 100 milliseconds after the cessation of a return stroke, the lightning channel is no longer sufficiently conducting to guide a dart leader. The lightning flash is then completed. Another stroke from the same part of a cloud must follow a completely new path, one created by a new stepped leader. For this reason, reports of ball lightning lasting as long as a few seconds were discounted or considered to be afterimages of the eye. There is still no satisfactory explanation for long-lived isolated electrical luminescence in the atmosphere.

7. Ball Lightning

Among the most mysterious manifestations of atmospheric electricity is the phenomenon of ball lightning or Kugelblitz. A glowing ball either (1) appears after a cloud-to-ground lightning flash and remains near the ground, or (2) is first seen in midair, descending

from a cloud or arising from no obvious cause, thereafter remaining aloft until it vanishes. Collisions with aircraft have caused verified damage, indicating that ball lightning is not restricted to ground level.

Most witnesses report that ball lightning is clearly visible in daylight although not as bright as an ordinary lightning flash. Some 85% of the observers agree that the size and brightness of the ball remains roughly constant throughout the period of observation and that no changes occur even immediately prior to its disappearance. A minority report brightening and color changes just before the ball vanishes. The colors red, orange, and yellow are most common, but most other colors are seen occasionally. Some researchers believe that blue or blue-white Kugelblitz is associated with higher energy, although there is no statistical basis for such an assertion. The reported diameters of Kugelblitz range between 5 and 80 cm with a median of about 30 cm. One survey lists three complexions of ball lightning: (1) a solid appearance with a dull or reflecting surface, or a solid core within a translucent envelope, (2) a rotating structure, suggestive of internal motions, (3) a structure with a burning appearance. The last type seems most common. About 1/3 of the witnesses detect internal motions or rotation of the ball itself, although this may depend on the distance of the observer.

A majority of onlookers report the motion of the ball to be slow (about 2 meters/sec.) and horizontal, with no apparent guidance by the wind or by the ground. One in six observers report speeds in excess of 25 m/sec. Several reports do indicate some guidance from telephone or power lines and by grounded objects. An odor of brimstone (burning sulfur) is often reported by nearby observers, especially at the time of decay.

The median lifetime of ball lightning is roughly four seconds, with 10% reporting over 30 seconds. Determination of lifetime is difficult because (1) subjective time during an exciting event is often in error,

and (2) few observers see a ball from the time it is created until the time it disappears. In any case, since an ordinary lightning channel can remain electrically conducting for only 0.1 second, a 10 second lifetime is two orders of magnitude beyond expectation.

Not long ago, considerable scientific discussion ensued on the question of whether ball lightning is a real phenomenon. Scientists believed that ball lightning could be (1) a retinal afterimage of a lightning flash, (2) an intense coronal point discharge near a lightning target below a thundercloud, (3) some burning or incandescent material thrown from the impact point of a lightning bolt. Today most researchers believe that Kugelblitz is a genuine electrical effect. A recent survey indicates that ball lightning may be extremely commonplace, but that the observer must be relatively close to the ball to be able to see it. Kugelblitz is probably invisible or indistinguishable in daylight at distances greater than 40 meters, which would explain why it is incorrectly believed to be a rare phenomenon.

The median distance between an observer outdoors and ball lightning is 30 meters. Sometimes ball lightning floats through buildings. The median distance between indoor observers and ball lightning is only 3 meters. The reported distance of the observer seems to be closely correlated with the reported size of the ball. A more distant observer is (1) less likely to notice luminous balls of small diameter, and (2) more likely to misjudge the diameter. The second difficulty is somewhat mitigated since in most cases of ball lightning terrestrial landmarks can be used for reference in estimating distances and sizes. On the other hand, estimates of the distance and size of a luminous sphere seen against the sky can be quite inaccurate.

In one report, a red lightning ball the size of a large orange fell into a rain barrel which contained about 18 liters of water. The water boiled for a few minutes and was too hot to touch even after 20 minutes. Assuming (1) that the water temperature was initially 20°C, (2) that 1 liter of water evaporated, and (3) that 17 liters were

raised to 90°C, one needs roughly 8×10^6 joules of energy (equivalent to 2 kg of TNT). For a ball 10 cm in diameter (the size of a large orange), the energy density is then 5×10^9 joule/m^3. But if all the air in a volume were singly-ionized, the energy density would be only 1.6×10^8 joule/m^3. Both the energy content and the energy density of ball lightning as derived from the singular rain barrel observation seem incompatible with the non-explosive character of most Kugelblitz. Although many lightning balls emit a loud explosive (or implosive) noise upon decay, effects characteristic of the release of energies of the order of 2 kg of TNT have rarely been reported (understandably if the observer was within 3 meters). Moreover, explosive or implosive decays have been noted indoors with no apparent heat or damage to nearby ceramic objects. Nevertheless, there are enough well-documented cases of extremely high energy Kugelblitz to make the water barrel report very believable. Probably there is a wide range of possible energies for a lightning ball, with the vast majority of Kugelblitz possessing energy densities less than that of singly-ionized air. The minimum possible energy of a lightning ball is that required to illumine a sphere about 25 cm in diameter with the brightness of a fluorescent lamp. With 10% efficiency, this means a source of 250 watts for 4 sec., or about 1000 joules of energy. We can only conclude with certainty that the energy of a lightning ball lies somewhere between 10^3 and 10^7 joules.

Theoretical efforts have focused on the energy estimate of the rain barrel observation. To maintain a fully-ionized, perhaps doubly-ionized mass of air requires either (1) a large amount of energy concentrated in a small volume and shielded from the surrounding air by a remarkably stable envelope, or (2) a continuous energy flow into a small volume, presumably by focusing power from the environment.

Theories which attempt to bottle fully-ionized plasma by magnetic fields or magnetovortex rings are faced with severe stability problems. There is no known way to contain plasma in the atmosphere for as long

as a few seconds. Moreover, a fully-ionized plasma ball would be hotter and probably less dense than the surrounding air, so that it would tend to rise rather than descend or move horizontally. Chemical combustion theories cannot explain the high energy content or the remarkable antics of the ball. Nuclear reactions would require an electric potential of at least 10^6 volts between the center and surface of the ball, and a mean free path for the ions as long as the potential gap. This situation seems unlikely, and faces similar problems of stability.

Theories which depend on an outside source of energy such as microwaves or concentrated d-c fields cannot explain how ball lightning can survive indoors.

If energies as high as several megajoules are not required, we can try other hypotheses. One suggestion is that the lightning ball is a miniature thundercloud of dust particles, with a very efficient charge separation process. Continuous low energy lightning flashes are illuminating the cloud. Another idea is that a small amount of hydrocarbon, less than that required for combustion, is suddenly subjected to strong electric fields. The hydrocarbons become ionized and form more complex hydrocarbon molecules which clump together. Eventually there is enough combustible material in the center to allow a burning core. If the concentration of hydrocarbon decreases, the ball disappears; if the concentration increases, the ball ignites explosively. (This represents the swamp gas theory for ball lightning).

Much depends on a reliable energy estimate for the Kugelblitz. If the energy is as high as indicated by the water barrel report, we have a real dilemma. At present no mechanism has been proposed for Kugelblitz which can successfully explain all the different types of reports. Probably several completely different processes can produce luminescent spheres in the atmosphere.

We conclude this section with summaries of several eyewitness reports of Kugelblitz.

The first few cases concern aircraft.

1. A commercial airliner (LI-2) was struck by ball lightning on 12 August 1956 while flying in the lower Tambosk region of the USSR. Before being struck, the aircraft had been flying at 3.3 km altitude through a slowly moving cold front which contained dense thunderclouds. During a penetration of one thundercloud, where the air temperature was about -3°C, the crew saw a rapidly approaching dark red almost orange fireball 25 to 30 cm in diameter to the front and left of the aircraft. At a distance of not more than 30 to 40 cm in front of the nose, the ball swerved and collided with a blade of the left propeller, exploded in a blinding white flash, and left a flaming tail along the left side of the fuselage. The sound of the explosion was loud enough to be heard over the noise of the engine. No substantial damage could be found. One of the left propeller blades had a small fused area 4 cm along the blade and less than 1 cm in depth. Around the damaged region was a small area of soot, which was easily wiped off.

2. In 1952, a T-33 jet trainer was flying near Moody AFB in Georgia. Because of a thunderstorm, the pilot was told to proceed to Mobile, Ala. As the T-33 rolled out onto a westerly heading at 4 km altitude, it collided with a "big orange ball of fire" that hit the nose head-on. The jolt was such that the student pilot believed there had been a midair collision with another aircraft. The low frequency radio compass no longer functioned, and they had to receive radio guidance to another base. On examination of the aircraft, they did not find a single mark or hole. The only damage was to the radio compass unit in the nose of the T-33 which was practically melted inside and was rendered useless. After the radio compass was replaced, everything functioned normally.

3. Another pilot distinguishes ball lightning from balls of St. Elmo's fire, and states that he has only seen "true" ball lightning near severe thunderstorms associated with squall lines, mountainous terrain, and significant cloud-to-cloud lightning. He defines "true" ball lightning as having the following characteristics: (1) diameters between 15 and 30 meters, (2) never originates outside the main thunderstorm cloud, (3) generates from a single point and expands in exactly the same manner as the fireball of an atomic explosion, but with a longer lifetime, (4) earphones detect soft sibilant hiss, easily distinguishable from crash static, which gradually increases in loudness concurrent with the growth of the ball, then rapidly decreases in loudness after peak brightness,(5) no apparent thunder. He considers smaller luminous balls seen near his aircraft to be St. Elmo's fire. If Kugelblitz within clouds can be as large as is estimated by this pilot, then ground-based observations reflect only weak manifestations of the phenomenon.

4. In Klass's book there is a remarkable photograph taken by an RCAF pilot in 1956, which seems to confirm the above observations. The pilot was flying westward at 11 km altitude over the foothills of the Canadian Rockies near Macleod, Alberta, through what he describes as the most intense thunderstorm he ever saw in North America. Cloud pillars extended above 12 km. The sun was setting behind the mountains and was obscured from view. The ground was dark. Through a break in the clouds he observed a bright stationary light with sharply defined edges "like a shiny silver dollar." The light was nestled deep within the thunderstorm, suspended above some cumulus reported at 4 km altitude. The object remained in view for 45 seconds as he flew across the cloud break. The diameter of the light is estimated to be at least 15 to 30 meters.

The following case is indicative of high-energy ball lightning.

5. At 3:30 p.m. on 26 April 1939, following a moderate rainstorm at Roche-fort-sur-Mer (France), an extremely brilliant flash of lightning branched into three directions. At the first impact point, a witness described a ball 15 to 20 cm in diameter and 2.5 meters above the ground which passed only 4 meters in front of him. He felt a breeze of air at the same time. The globe climbed an iron cable which it melted and pulverized, producing smoke in the process. The electrical conduits of an adjoining house were burned and the meter was damaged. The observer, who was installing a gas pipe, received a shock. At the second impact point several workers saw a globe also 15 to 20 cm in diameter touch the top of a crane. There ensued a great explosive noise accompanied by a blue spark as large as an arm which flew 40 meters and struck the forehead of a dock worker, knocking him to the ground. A dozen shovelers working 10 to 50 meters from the crane received shocks and were knocked over, one being thrown 60 cm into the air. The shovels were torn from their hands and thrown 3 or 4 meters away. No smoke or odor was perceived. At the crane, current flowed along the electric cable, boiled the circuit breaker board and the windings of the crane's electric motor. The chief electrician received a violent shock and was unable to free his hands from the controls. At the third impact point, a ball of fire as large as two fists hit a lightning rod and descended along the conductor to the ground, disappearing behind a building. Two workers saw a ball of fire roll very rapidly along the ground.

6. In Hanover, Germany during a July thunderstorm in 1914, a fire-ball the size of an egg came through the window, left a burnt spot near the ceiling, travelled down the curtain, and disappeared in the floor. No burnt marks were found in the floor or curtains, but the ceiling had a slightly charred mark the size of a penny.

Cases like these are not unusual. Ball lightning has been known to cut wires and cables, to kill or burn animals and people, to set fire to beds and barns, to chase people, to explode in chimneys, and to ooze through keyholes and cracks in the floor. It has even been reported in the passenger compartment of a DC-3 aircraft. Moreover, lightning conductors are not always able to dissipate the energy of Kugelblitz. In St. Petersburg, Fla., during the summer of 1951 an elderly woman was found burned to death in an armchair near an open window. Above one meter, there were indications of intense heat -- melted candles, cracked mirror, etc. A temperature of 1400°C would have been needed to produce such effects. But below one meter there was only one small burned spot on the rug and the melted plastic cover of an electric outlet. A fuse had blown, stopping a clock in the early morning hours. Since lightning is common near St. Petersburg, this case has all the marks of Kugelblitz.

7. "On 3 March 1557, Diane of France, illegitimate daughter of Henri II, then the Dauphin, married Francois de Montmorency. On the night of their wedding, an oscillating flame came into their bedroom through the window, went from corner to corner, and finally to the nuptial bed, where it burnt Diane's hair and night attire. It did them no other harm, but their terror can be imagined."

8. Coronal Effects

A sharp point which extends from a charged conducting surface is a region of maximum electric field. During a thunderstorm, therefore, we can expect large electric fields near trees, towers, tall buildings, the masts of sailing ships, and all other points rising from the earth's conducting surface.

If the electric field becomes large enough, avalanche processes can cause electrical breakdown of the surrounding air and a sustained coronal discharge. Coronal effects may transfer more charge between

cloud and ground than does lightning.

St. Elmo's fire appears as a glowing luminescence hovering above a pointed object or near a wire conductor. It is usually oval or ball shaped, between 10 and 40 cm in diameter, and has a glowing blue-white appearance. Its lifetime exceeds that of ball lightning, sometimes lasting several minutes. The decay is silent but may be sudden or slow. Sometimes hissing or buzzing noises can be detected.

The primary difference between ball lightning and St. Elmo's fire is that St. Elmo's fire remains near a conductor. It has been observed to move along wires and aircraft surfaces, sometimes pulsating. Foo-fighters are probably a manifestation of St. Elmo's fire. Eye-witness reports of coronal discharge are presented in Section 14 . Here is an account of St. Elmo's fire from the same pilot who gave observation 3 of the previous section.

"The smaller 'ball lightning' I have always associated as being the phenomenon known as St. Elmo's fire; however, St. Elmo's fire generally consists of an infrequent blanket covering the leading edges and trailing edges of an aircraft. It does not blind or brighten but is merely irritating as it prevents clear radio reception. The 'small ball' formation varies in size from two inches (5 cm) to a foot and a half (46 cm) in diameter and generally 'rolls around' the aircraft apparently unaffected by the movement of the aircraft. On one occasion a small ball (about six inches (15 cm) in diameter) of yellowish-white lightning formed on my left tiptank in an F-94B then rolled casually across the wing, up over the canopy, across the right wing to the tiptank and thence commenced a return, which I didn't note, but I was advised by my observer that it disappeared as spontaneously as it had arisen. I have seen this form several times but rarely for as long as a period which I would estimate to be about two minutes in duration. Sometimes the balls are blue, blue-green, or white though it appears to favor the blue-green and yellow-white. It might be of interest to you to know that subsequent to the 'small ball' rolling

over my aircraft, the aircraft was struck three times by conventional lightning bolts which melted four inches (10 cm) off the trailing edge of each tiptank and fused about a four inch section covering my tail lights."

9. Ignis Fatuus

In swamps and marshes, methane, CH_4 (and also phosphine PH_3), is released by decaying organic matter. When the methane ignites, either by spontaneous combustion or by electrical discharges produced during times of thunderstorm activity, luminous globes which float above the swamp can be seen. These are not plasma effects, but resemble them in appearance. They are called Ignis Fatuus (foolish fire), jack-o-lanterns, will-o-the-wisp, or simply swamp (or marsh) gas. The colors are reported to be yellow, sometimes red or blue. Thunderstorms and other electrical activity around swamps seem to stimulate this effect.

Occasionally observers have placed their hands into these luminescent gases without feeling any heat. Dry reeds did not catch fire. Copper rods did not heat up. Occasionally however paper was ignited.

There is little doubt that Ignis Fatuus is the source of some ghost stories and UFO reports.

10. Tornado Lightning

In certain situations, cold dry air (from the Rocky Mountains) flows over warm moist air (from the Gulf of Mexico) which is moving in a different horizontal direction. As a result, wind shear and strong convection produce active thunderstorm cells along a line of instability some tens of kilometers ahead of the cold front. These thunderstorm cells and the opaque clouds connecting them are known as a squall line. Squall lines are the source of most tornadoes.

The characteristic feature of the tornado is the funnel-shaped cloud that hangs from the sky and moves around like the trunk of an

elephant. The destructive capability of the tornado is the result of an extremely sudden pressure drop of roughly 0.1 atmosphere between the inside and outside of the funnel. Winds can range in speed from 100 to 330 m/sec.

Without question, the most concentrated and powerful manifestations of atmospheric electricity occur in conjunction with tornadoes. Tornadoes are associated with continuous lightning, point discharges, and ball lightning. Early theories of the 19th century maintained that the tornado is a conducting channel for lightning between cloud and ground. Present thought attributes the origin of tornadoes to violent convective air motions near squall lines.

Although many convective events, such as isolated thunderstorms, dust devils, hurricanes, etc., occur in the atmosphere, these have energy concentrations much smaller than that of a tornado. Consequently, several researchers believe that a tornado can be maintained only by an intense and continuous lightning discharge along its axis. Such a discharge heats the air within the funnel, thereby causing violent updrafts and vortex motions. Whether or not this theory is correct, there is little doubt that the electrical power generated during a single tornado event is at least 2×10^{10} watts, or about 1/10 of the combined power output of all the electrical generators in the United States.

From radio emissions (spherics), it is estimated that about 20 lightning flashes occur each second in a tornado cloud. Assuming 20 coulombs per lightning discharge, the average current flowing through a tornado is about 400 amperes. Magnetic field measurements near a tornado indicate that such a current is not unreasonable. Using 10^9 joules per lightning flash, we find 2×10^{10} watts for the electrical power generated by a tornado.

Such estimates may be too conservative. Tornado lightning is reported to be brighter, bluer, and more intense than its thunderstorm counterpart. Long before a tornado is observed, lightning

interlaces the clouds. About 15 minutes prior to the appearance of the funnel, the lightning becomes intense and continuous. After the funnel descends, the sky is reported to be in a blaze of light with never ceasing sheet lightning.

Large hailstones are commonly produced both by tornadoes and by severe isolated thunderstorms. Hail is closely correlated with intense electrical activity. Observations of burned, wilted, and dehydrated vegetation, and odors of brimstone (burning sulfur) provide further evidence of electrical action. The tornado funnel is usually preceded by a peculiar whining sound, a noise indicative of coronal discharge.

Eyewitness accounts are interesting in the present context because it has been suggested that many UFOs are luminous tornado clouds whose funnels have not reached the ground:

1. "After a tornado passed over Norman, Oklahoma and headed north, personnel at Tinker Field heard a sharp hissing sound overhead combined with a lowpitched continuous roar. We were conscious of an unusual and oppressive sensation. The noise source was definitely above us. When it was nearest us, I saw the sky above gradually grow lighter, then fade to black. The light was greenish in color. Associated with the light was a strong sensation of heat radiating downward. The noise increased in volume and then faded out as though it came from the south and passed us going north. The rain had stopped while this phenomenon was overhead."

2. "As the storm was directly east of me, I could see fire up near the top of the funnel that looked like a child's Fourth of July pinwheel. There were rapidly rotating clouds passing in front of the top of the funnel. These clouds were illuminated only by the luminous band of light. The light would grow dim when these clouds were in front, and then it would grow bright again as I could see between the clouds. As near as I can explain, I would say that the light

was the same color as an electric arc-welder but very much brighter. The light was so intense that I had to look away when there were no clouds in front of it."

3. "The funnel from the cloud to the ground was lit up. It was a steady deep blue light -- very bright. It had an orange-color fire in the center from the cloud to the ground. As it came along my field, it took a swath about 100 yards wide. As it swung from left to right, it looked like a giant neon tube in the air, or a flagman at a railroad crossing. As it swung along the ground level, the orange fire or electricity would gush out from the bottom of the funnel and the updraft would take it up in the air causing a terrific light -- and it was gone! As it swung to the other side, the orange fire would flare up and do the same."

4. "There was a screaming, hissing sound coming directly from the end of the funnel. I looked up, and to my astonishment I saw right into the heart of the tornado. There was a circular opening in the center of the funnel, about fifty to one hundred ft. (15 to 30 m) in diameter and extending straight upward for a distance of at least half a mile (800 m), as best I could judge under the circumstances. The walls of this opening were rotating clouds and the whole was brilliantly lighted with constant flashes of lightning, which zig-zagged from side to side."

5. "We looked up into what appeared to be an enormous hollow cylinder bright inside with lightning flashes, but black as blackest night all round. The noise was like ten million bees plus a roar that beggars all descriptions."

6. "A few minutes after the storm passed, there was a taste and smell in the air like that of burnt sulfur. The air was clammy,

and it was hard for me to breathe. The sensation was like being smothered."

7. "... burned up the trees that lay within its circumference, and uprooted those which were upon its line of passage. The former, in fact, were found with the side which was exposed to the storm completely scorched and burned, whereas the opposite side remained green and fresh."

8. "...suddenly it turned white outside. This whiteness definitely was not fog. I would say it appeared to be giving off a light of its own."

9. "The beautiful electric blue light that was around the tornado was something to see, and balls of orange and lightning came from the cone point of the tornado."

10. "The most interesting thing I remember is a surface glow -- some three or four feet deep -- rolling noise, etc."

If a researcher had never heard of a tornado, and were asked to compare the eyewitness accounts of tornadoes (such as these) with those concerning UFOs, he would probably find the tornado reports to be more fantastic and incredible. Luminous tornado clouds with no funnels to the ground are possible causes of several UFO reports.

11. Dust Devil Electricity

During the heat of the day, the air temperature is high at the desert floor but decreases rapidly with height. At some critical temperature gradient (called the autoconvective lapse rate) violent upward convection of heated air occurs. Under certain desert conditions, the upward convection may be rather intense in small areas.

Rapidly rising air is replaced by cooler air which flows inward horizontally and asymmetrically, thereby creating a vertical vortex funnel. Such a desert vortex made visible by dust and sand particles, is known as a dust devil. Unlike the tornado, however, the dust devil begins from the ground and rises upward. Although it can sometimes blow a man over, it is much less powerful than a tornado.

Recent measurements indicate that strong electric fields are generated by dust devils. The precise nature of the charge separation process is not understood, but in this case at least, the electrical effects are almost certainly the result of convective motions and particle interactions.

Luminescent effects of dust devils have never been reported and would be extremely difficult to detect in the daytime. Since dust devils do not occur at night when the desert floor is cooler than the air above, this phenomenon can not explain UFOs reported at night.

12. Volcano Lightning

Undersea volcanic eruptions began on the morning of 14 November 1963, only 23 km from the southern coast of Iceland, where the water depth was 130 m. Within 10 days an island was created which was nearly 1 km long and 100 m above sea level. Motion pictures showed clouds rising vertically at 12 m/sec to an altitude of 9 km. The cloud of 1 December contained intense, almost continuous light, presumably the result of large dust particles and perhaps electret effects of sulfur.

Aircraft flights through the volcanic cloud were made during periods of no lightning. Large electric fields were measured, sometimes exceeding 11,000 volt/m.

The production of lightning by volcanos is of considerable interest for atmospheric electricity. Nevertheless, there is no evident relation between volcano lightning and UFO reports.

13. Earthquake-Associated Sky Luminescence

Intense electrical activity has often been reported prior to, during, and after earthquakes. Unusual luminescent phenomena seen in the sky have been classified into categories: (1) indefinite instantaneous illumination: (a) lightning (and brightenings), (b) sparks or sprinkles of light, (c) thin luminous stripes or streamers; (2) well-defined and mobile luminous masses: (a) fireballs (ball lightning), (b) columns of fire (vertical), (c) beams of fire (presumably horizontal or oblique), (d) luminous funnels; (3) bright flames and emanations: (a) flames, (b) little flames, (c) many sparks, (d) luminous vapor; (4) phosphorescence of sky and clouds: (a) diffused light in the sky, (b) luminous clouds. The classification is somewhat ambiguous, but is rather descriptive of luminous events associated with earthquakes.

The earliest description of such phenomena was given by Tacitus, who describes the earthquake of the Achaian cities in 373 B.C.E. Japanese records describe luminous effects during many severe earthquakes. In the Kamakura Earthquake of 1257, bluish flames were seen to emerge from fissures opened in the ground.

Flying luminous objects are mentioned in connection with the earthquake at Yedo (Tokyo) during the winter of 1672. A fireball resembling a paper-lantern was seen flying through the sky toward the east. During the Tosa earthquake of 1698, a number of fireballs shaped like wheels were seen flying in different directions. In the case of the Great Genroku Earthquake of 31 December 1730 in Tokaido, luminous "bodies" and luminous "air" were reported during the nights preceding the day of severest shock. Afterwards a kind of luminosity resembling sheet lightning was observed for about 20 days, even when there were no clouds in the sky. One record of the Shinano Earthquake of 1847 states: "Under the dark sky, a fiery cloud appeared in the direction of Mt. Izuna. It was seen to make a whirling motion and then disappeared. Immediately afterward, a roaring sound was

heard, followed by severe earthquakes." In Kyoto in August, 1830, it is reported that during the night preceding the earthquake luminous phenomena were seen in the whole sky; at times, illumination emitted from the ground was comparable in brightness to daylight. In the Kwanto Earthquake of 1 September 1923, a staff member of the Central Meteorological Observatory saw a kind of stationary fireball in the sky of Tokyo.

The earthquake at Izu, 26 November 1930, was studied in detail for associated atmospheric luminescence. Many reports of sightings were obtained. The day prior to the quake, at 4 p.m., a number of fishermen observed a spherical luminous body to the west of Mt. Amagi, which moved northwest at considerable speed. Fireballs (ball lightning) and luminous clouds were repeatedly observed. A funnel-shaped light resembling a searchlight was also seen. Most witnesses reported pale blue or white illumination, but others reported reddish or orange colors.

That large electrical potentials can be created by the slippage or shearing of rocks is not surprising. Nevertheless, associated ball lightning and luminous clouds are of significance to this study. Of possible importance is the use of electrical measurements to provide some advance warning of an impending earthquake.

14. Mountaintop Electricity

Mountains are sharp projections which rise from the conducting surface of the earth. The electrical potential of a mountain is essentially equal to that of the surrounding lowlands. Consequently, when an electric field is set up between cloud and ground, the potential gradient (or electric field strength) reaches a maximum between the mountaintop and the overlying clouds.

The large potential gradient which often exists on a mountaintop may give rise to a number of events related to coronal discharge.

Physiological effects of large electric fields are frequently reported by mountaineers. Many of these effects are also occasionally reported in connection with UFOs. In this section we summarize eyewitness reports from mountaintops.

1. A graduate student of the University of Colorado was climbing Chimborazo, a high and isolated mountain in Ecuador. The summit is a large flat plateau 400 meters in diameter and 6266 meters above sea level. He and a companion left their camp at 5700 meters on the morning of 1 March 1968. At 10 a.m. clouds started forming at the peak, and a small amount of graupel began to fall. When they reached the summit, between 2 and 2:30 p.m., there was considerable cloudiness. Just as they were about to take the traditional photograph of conquest, the graupel began to fall more heavily. Suddenly they felt an odd sensation about their heads, described as mild electric shocks and crackling and buzzing sounds. Their aluminum glacier goggles began to vibrate, and their hair stood on end. The climbers dived into the snow and waited. Thunder was heard in the distance. They found that whenever they raised their heads off the ground, the electrical effects recurred. It seemed as if there were an oppressive layer 50 cm above the surface. After waiting half an hour, the climbers crawled off the peak on their bellies. They proceeded in this manner for an hour and a half, 400 meters across the plateau and down the slope. After descending 60 meters, they found they could stand up. By this time the fall of graupel and the sounds of thunder had ceased.

During the 1870's and 1880's, the Harvard College Observatory maintained a meteorological station at the top of Pike's Peak. The journal of this expedition makes fascinating reading:

2. "16 July 1874. A very severe thunderstorm passed over the summit between 1 and 3 p.m., accompanied by mixed rain and hail. Sharp

flashes and reports came through the lightning arrester, to the terror of several lady visitors; outside the build g the electric effects were still more startling. The strange crackling of the hail, mentioned before, was again heard, and at the same t . the observer's whiskers became strongly electrified and repellent, and gave quite audible hissing sounds. In spite of the cap worn, the observer's scalp appeared to be pricked with hundreds of red hot needles, and a burning sensation was felt on face and hands. Silent lightning was seen in all directions in the evening, and ground-currents passed incessantly through the arrester."

3. "21 July 1874. Not only did the constant crackling of the fallen hail indicate the highly electrified state of the summit, but from the very rocks proceeded a peculiar chattering noise, as if they were shaken by subterranean convulsions."

4. "25 May 1876. At 6 p.m. continued thunder was heard overhead and southeast of the peak. The arrester was continually making the usual crackling noise. About this time, while outdoors, the observer heard a peculiar "singing" at two or three places on the wire very similar to that of crickets. When the observer approached near one of these places the sound would cease, but would recommence as soon as he withdrew two or three feet distant."

5. "18 August 1876. During the evening the most curiously beautiful phenomenon ever seen by the observer was witnessed, in company with the assistant and four visitors. Mention has been made in journal of 25 May and 13 July of a peculiar "singing" or rather "sizzing" noise on the wire, but on those occasions it occurred in the daytime. Tonight it was heard again, but the line for an eighth of a mile (200 m) was distinctly outlined in brilliant light, which was thrown cut from the wire in beautiful scintillations. Near us we could observe these little jets of flame very plainly. They were invariably in the shape of a quadrant, and the rays concentrated at the surface of

the line in a small mass about the size of a currant, which had a bluish tinge. These little quadrants of light were constantly jumping from one point to another of the line, now pointing in one direction, and again in another. There was no heat to the light, and when the wire was touched, only the slightest tingling sensation was felt. Not only was the wire outlined in this manner, but every exposed metallic point and surface was similarly tipped or covered. The anemometer cups appeared as four balls of fire revolving slowly round a common center; the wind vane was outlined with the same phosphorescent light, and one of the visitors was very much alarmed by sparks which were plainly visible in his hair, though none appeared in the others'. At the time of the phenomenon snow was falling, and it has been previously noticed that the "singing" noise is never heard except when the atmosphere is very damp, and rain, hail, or snow is falling."

6. "16 June 1879. (During afternoon). One of those electric storms peculiar and common to Pike's Peak prevailed. A queer hissing sound issued from the telegraph line, the wind-vane post, and another post standing in a deep snow drift near by. Observer stepped out to view the phenomenon, but was not standing in the snow drift long, when the same buzz started from the top of his head; his hair became restless, and feeling a strange creeping sensation all over his body, he made quick steps for the station."

7. "10 July 1879. At 5 p.m. the hail turned to snow, and ceased at 5:30 p.m., the wind being gentle throughout. On stepping to the door at 6 p.m., observer states that he felt a peculiar sensation about the whole body, similar to that of an awakening limb after being benumbed; that his hair stood straight out from his head, and seemed to produce a peculiar "singing" noise like that of burning evergreens; the telegraph line and all metallic instruments producing a noise like

that of swarming bees. When he put on his hat, the prickly sensation became so intense that he was compelled to remove it, his forehead smarting as though is had been burned for fully three hours later. At 7 p.m. the electric storm had ceased."

With the exception of tornado situations described earlier (where heat is also present), it is not likely that electrical sensations are anywhere more intense than on mountaintops. UFO reports sometimes indicate creepy, crawling sensations, much less pronounced, however, than those experienced by mountaineers.

15. Meteor Ionization and Meteor Sounds

A meteor is a streak of light produced by the interaction with the atmosphere of a solid particle (or meteoroid) from interplanetary space. Most meteoroids, particularly those that appear on schedule during certain times of the year, are probably dust balls which follow the orbit of a comet. When they enter the atmosphere they produce short-lived streaks of light commonly known as shooting stars.

A fireball or bolide (Greek for javelin) is a meteor with a luminosity that equals or exceeds that of the brightest planets (apparent magnitude -5). A solid object called a meteorite may be deposited on the earth's surface after a bolide, but never after scheduled meteor showers. The appearance of a bolide is random, and not correlated either in space or in time with comet orbits and the usual meteor showers. Bolides are believed to be caused by solid fragments from the asteroid belt. whereas the scheduled meteors are caused by dust balls from cometary orbits.

When a meteoroid passes through the upper atmosphere, a shock wave is generated, accompanied by intense heating of the surrounding air and the meteoroid surfaces. Atoms which boil off the meteoroid surface possess thermal speeds of about 1 km/sec and directed velocities of up to 72 km/sec. They collide with surrounding air molecules, and create an envelope of ionization and excitation. A meteorite only a few tens

of centimeters wide may be surrounded by an ionized sheath of gas some tens of meters or more in diameter. De-excitation and recombination processes give rise to the long visible trail behind the meteoroid. Meteor trails are visible at altitudes between 110 and 70 km.

The brightest bolides can cast shadows over a radius of 650 km. To be as bright as the full moon, meteoroids of at least 100 kg are required. About 1500 meteoroids enter the earth's atmosphere each year, each with a mass greater than 100 kg.

The visual appearance of a bolide differs considerably from that of a shooting star. Vivid colors and color changes are common. Bolides have been seen to break apart, with fragments circling slowly on the way down or flying in a line or in an apparent formation. The trajectory of a bolide can appear almost horizontal to the observer. Because of the extreme brightness and the large diameter of the ionization envelope, distances to bolides are always underestimated, particularly if it should flare up toward the end of the descent. Odors of brimstone near the impact point have also been reported.

Meteor trains associated with bolides sometimes remain luminescent for an hour or so. Such a train may appear as a glowing column about one kilometer in diameter. The mechanism which allows certain meteor trains to glow for so long a time is not known. Radar trails of ordinary meteors last only 0.5 sec. Spectral analysis of glowing meteor trails reveals many bright emission lines from excited air atoms. Radiation from the hot surface of a meteoroid has also been detected on rare occasions. These emission lines reveal only common elements (such as iron, sodium, magnesium, and other minerals), implying a chemical composition similar to the earth and to the asteroids. During the day, a bolide train is seen as a pillar of dust at lower altitudes rather than as a glowing column in the upper atmosphere.

Some minutes after exceptionally bright bolides, some witnesses have heard sounds decribed as thunder, the boom of a cannon, rifle or

pistol fire, etc. These sounds are produced by the fall and deceleration of a massive meteorite or of several fragments.

There are also a significant number of reports concerning sounds heard while the bolide was still descending from the sky, perhaps a hundred kilometers above the ground. These sounds are described as hissing, swishing, whizzing, whirring, buzzing, and crackling, and are attributed to bolides with an average apparent magnitude of -13 (about the brightness of the full moon). Such noises could not have propagated all the way from the meteorite, since sound travels too slowly.

At one time it was believed that people who observed bolides imagined the sounds, as a psychological association with noise from sparklers and other fireworks. Meteor sounds are now regarded as physical effects. On several occasions the observer first heard the noise and then looked upward to seek the cause. (Similar noise has also been reported during times of auroral activity.)

One hypothesis is that low frequency electromagnetic radiation is emitted by bright bolides and detected by human sense organs. Human subjects exposed to radar beams of low intensity have perceived sensations of sound described as buzzing, clicking, hissing, or knocking, depending on the transmitter characteristics. A pulse-modulated signal with a peak electromagnetic radiation flux of 4 watt/m^2 at the observer was perceived as sound by subjects whose audible hearing was good above 5 kHz. If the background noise exceeded 90 decibels, the radio frequency sound was masked, but earplugs improved the reception.

During the fall of one of the largest bolides, near Sikhote-Alin, near Vladiovostok (USSR), an electrician on a telephone pole received a strong electric shock from disconnected wires at the instant the bolide became visible. The shock may have been due to other causes, but the possibility of strong electromagnetic effects is not ruled out.

At present, measurements made during smaller meteor events (of the dust ball variety) give no indication of significant radio emission. Magnetic effects are insignificant.

Another conjecture is that atomic collisions in the vicinity of a meteorite bring about a separation of charge along the ionization trail of the bolide. For coronal discharge effects to occur at ground level, however, the bolide would have to separate many thousands (or even tens of thousands) of coulombs about 30 km. along its ionization trail. Such a process seems unlikely.

The noises which appear simultaneously with the bolide are not understood. If strong electrical fields accompany a bolide, other effects such as lightning or ball lightning may occur. Both lightning and ball lightning have occasionally been reported in clear non-stormy weather. There are also several reports of large chunks of ice falling out of cloudless skies. They are not believed to have fallen from aircraft. The ice chunks may arise from electrical effects of bolides, or (more probably) may be the meteorites themselves.

16. Micrometeorites of Antimatter

The existence of anti-protons, anti-electrons, anti-neutrons, etc. is no longer a subject for speculation. A particle and its anti-particle annihilate one another on contact, creating radiant energy. Consequently, we do not find antimatter on the earth. It is not known how much antimatter exists elsewhere in the universe.

In June of 1908, a bolide of enormous magnitude fell near the Tunguska River about 800 km. north of Lake Baikal in Siberia. The light was possibly as bright as the sun and was seen over a radius of 700 to 1000 km. Acoustic noises from the shock were heard as far away as 1000 km. No trace of a crater has ever been found, but within a radius of 40 km., exposed trees were flattened with their tops pointing radially away from the epicenter. Witnesses felt intense heat on their skin. Metal objects near the impact point were melted. Trees were scorched for 18 km around. An earthquake was detected on seismographs at the Irkutsk Magnetic and Meteorological Observatory which corresponds

in time to the impact of the bolide. Barometric waves circled the globe. Magnetic disturbances were reported on many continents. The energy released by the Tunguska bolide is estimated between 10^{16} and 10^{17} joules (the energy range of hydrogen bombs).

Several million tons of dust may have been injected into the atmosphere. For several weeks after the event, luminous clouds in Europe and Western Siberia made it possible in certain areas tc read at midnight under the open sky. The observatory at Irkutsk could not see the stars. A traveller noted in his diary that night never came. The nature of these luminous clouds is still a matter of debate.

The composition of the bolide and the cause of the explosion are not known. A very massive meteorite should impact with the ground and leave a large crater (even though the meteorite and part of the ground would be immediately vaporized). The Tunguska bolide, however, apparently exploded some 3 km or so above ground level.

Several hypotheses have been advanced concerning the nature of the bolide and the explosion: (1) a meteorite of large initial mass with an almost horizontal trajectory; (2) a collision with a comet containing an ice or dust nucleus; (3) a high energy chemical reaction initiated by radicals in a head of a comet; (4) a nuclear explosion initiated by the shock wave of a large meteorite; (5) an antimatter meteoroid of a few hundred grams.

The first two hypotheses are conventional. Even so, it is extremely difficult to evaluate quantitatively the optical, acoustical, and thermal effects that might occur under all possible circumstances. The remaining hypotheses were proposed to explain the thermal effects.

The fourth hypothesis seems unlikely. A fission reaction of such magnitude would require that large almost-critical masses of fissionable material be suddenly brought together. A fusion reaction would require an initial temperature of several million degrees Kelvin. Neither of these possibilities seems reasonable.

The fifth hypothesis has measurable consequences. When matter and antimatter come into contact, they annihilate each other, and produce gamma ray, kaons, and pions. If an antimatter meteoroid were to collide with the atmosphere, negative pions would be produced. The nuclei of the surrounding air atoms would absorb the negative pions and release the neutrons.

Nitrogen nuclei would capture the neutrons and be turned into radioactive carbon 14. As carbon dioxide, the radiocarbon would be dispersed throughout the atmosphere and be absorbed by living organisms.

The energy of the Tunguska bolide was estimated from a study of the destruction that occurred. The initial quantity of antimatter and the amount of radioactive carbon dioxide produced was then estimated. Sections of trees which grew in 1908 were analysed for radiocarbon. The conclusion of several scientists is that the Tunguska meteor was probably not composed of antimatter. The best guess is that a comet collided with the earth in June, 1908.

Nevertheless, the hypothesis of antimatter meteorites is intriguing. If a significant amount of antimatter does exist in the universe, it is possible that antimatter supernovae might eject tiny grains of anti-mass at relativistic speeds. Such a grain might penetrate our galaxy and collide with the earth's atmosphere. Entering at relativistic speeds, the grain might survive until it reached the troposphere. A fraction of a microgram of antimatter would destroy an equal mass of matter and release many megajoules of energy, perhaps creating luminous spheres. However, the annihilation of a fast antimatter meteorite has never been calculated in detail, and possible visual effects are unknown. Moreover, since small grains of antimatter would leave virtually no trace, this hypothesis remains as pure speculation.

17. Plasma Theories for UFOs

Two articles and one popular book have been written on plasma interpretations of UFOs by P. J. Klass. Klass was impressed by reports of UFOs in close association with high tension power lines near Exeter, New Hampshire. Many popular books assert that UFOs are extraterrestrial spaceships which hover over power lines to refuel. Klass believes that some UFOs are an unusual form of coronal discharge analogous to St. Elmo's fire.

In his first article, ball lightning is assumed to be a manifestation of extreme coronal discharge. Klass points out that ball lightning and the Exeter UFOs compare favorably with regard to color, shape, sound, dynamics, lifetime, and size. According to those reports, the diameters of the UFOs ranged from the size of a basketball to 60 meters. This size range may be due to the difficulty of making distance estimates at night without visible reference points. Exeter is close enough to the sea for salt to form on high tension wires and had very little rainfall that summer to wash away the salt, thus providing points from which coronal discharge could occur.

Criticisms are (1) that other seacoast towns with high tension wires did not report UFO activity during the drought period, and (2) the luminosity, although near the wires, was occasionally some angular distance away.

Klass also examined other UFO reports including those seen at aircraft altitudes. In his second article, which is concerned with the general UFO problem he asserts that ball lightning may occur under many situations, and consequently may be the cause of many unusual UFO sightings. Various aspects of ball lightning and the laboratory creation of luminous plasma by microwaves and gas discharges are briefly discussed. Klass argues that plasma blobs would have the same characteristics and would cause the same effects as those occasionally attributed to UFOs, including the abrupt (sometimes explosive) disappearances, maneuvers near aircraft, rapid accelerations, stalled automobiles, heat, prickling sensations, irritated eyes, etc. He discusses one observation of an UFO seen through Polaroid sunglasses and one report of an agitated magnetic compass.

The book, *UFOs Identified,* is an expanded version of the two articles, and contains background of the author's investigation. He discusses ball lightning, the behavior and appearance of UFOs, radar and photographic evidence, the various reactions to his articles, and

an account of a couple who claim they were held prisoner in an UFO. The book does not attempt to summarize any of the fundamental principles of atmospheric electricity, plasma physics, or atmospheric dynamics.

About reports of automobiles stalled near UFOs, Klass writes: "Because a plasma contains a cloud of electrified particles, there is no doubt that if an auto battery were enveloped by such a plasma the battery could be short-circuited. But it is difficult to explain how an UFO-plasma could gain entry to the car battery in the engine compartment without first dissipating its energy to the metal body of the car. Another possible explanation is based on the fact that an electric charge in the vicinity of a conducting surface, such as a car's hood, creates a mirror image of itself on the opposite side of the conducting surface." The implication here is mistaken: the image charge discussed in electrical theory is not an actual charge on the other side of a metal shield, but a mathematical fiction that is used to describe the alteration of the electric field by redistribution of electric charges on the metal shield.

Alleged automobile malfunctions are discussed in Section III, Chapter 5 of this report, and was purposely omitted here. However, a few remarks may be in order. As Klass points out, some motorists have reported that both headlights and engine failed. Others have reported that only the engine or only the headlights failed. Often police cars have chased UFOs for tens of kilometers so engine failure does not always occur. Moreover, no unusual magnetic patterns have so far been detected in auto bodies.

When radar was secretly being developed by the RAF prior to the London Blitz (World War II), some of the local people of Burnham-on-Crouch were convinced that the mysterious masts recently erected had stopped passing automobiles. Presumably when the purpose of radar became known, cars were no longer stalled.

In addition to ball lightning and coronal discharge, he also suggests tornado clouds with no funnel to ground, luminescence generated

during snowstorms, rotating dust vortices, and small charged ice crystals. Another one of his ideas is that occasionally a highly charged aircraft may release ions into a large wingtip vortex. The vortex remains luminous for awhile, to be encountered shortly thereafter by another aircraft. Although coronal effects occur on aircraft surfaces, it is unlikely that a lightning ball could detach from an aircraft and remain luminous for more than a few seconds.

18. Plasma UFO Conference

On 27 and 28 October 1967, several physicists expert in either plasma physics or atmospheric electricity met in Boulder, Colo. to discuss the UFO problem with staff members of this project. Participants in the plasma UFO conference were:

Marx Brook: New Mexico Inst. of Mining and Technology
Keith A. Brueckner: University of California (San Diego)
Nicholas C. Christofilos: University of California (Livermore)
Ronald T. H. Collis: Stanford Research Institute
Edmond M. Dewan: Air Force Cambridge Research Lab.
Herman W. Hoerlin: Los Alamos Scientific Lab.
Bernd T. Matthias: University of California (San Diego)
Arnold T. Nordsieck: Santa Barbara, California
Marshall N. Rosenbluth: James Forrestal Research Center
John H. Taylor: University of California (San Diego)
UFO Study Members

Various aspects of atmospheric electricity were reviewed, such as ball lightning, and tornado and earthquake luminescence. Unusual UFO reports were presented for discussion. These included a taped report by a B-47 pilot whose plane was paced for a considerable time by a glowing object. Ground radar reported a pacing blip which appeared to be 16 km from the aircraft. After review the unanimous conclusion was that the object was not a plasma or an electrical luminosity produced by the atmosphere.

Participants with a background in theoretical or experimental plasma physics felt that containment of plasma by magnetic fields is not likely under atmospheric conditions for more than a second or so. One participant listed the characteristics that would be expected to accompany a large plasma. These are (1) thermal emission, (2) production of ozone and odor of N_2O, (3) convective air motions, (4) electrical and acoustic noise, (5) unusual meteorological conditions.

Another plasma physicist noted that a plasma explanation of certain UFO reports would require an energy density large enough to cause an explosive decay. Atmospheric physicists, however, remarked that several reports of ball lightning do indicate unusually high energy densities.

All participants agreed that the UFO cases presented contained insufficient data for a definitive scientific conclusion.

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Chapter 8

Balloons - Types, Flight Profiles and Visibility

Vincent E. Lally

1. Types of balloons

Three kinds of balloons can give rise to UFO sightings: neoprene or rubber balloons which expand during ascent from six feet to 30 ft. in diameter; polyethylene balloons which are partially inflated on the ground and fill out at float altitude to a diameter of 100 ft. to 400 ft.; and small super-pressure balloons called "ghost" balloons.

Neoprene balloons

When neoprene or rubber balloons which are used to carry radiosondes begin their ascent, they have a diameter of six feet. They continue to expand as they rise, and the balloons that reach an altitude of 140,000 ft. are 55 ft. in diameter. All of these balloons shatter when they reach a volume at which a weakness develops. One of these balloons has flown as high as 156,000 ft., higher than the largest polyethylene balloons. These balloons are used to make measurements of air temperature, humidity, and winds. Approximately 90% of the neoprene balloons reach 80,000 ft.; probably 50% of them reach 100,000 ft. The neoprene balloon at any altitude has a brighter reflectance than either the polyethylene or the "ghost" balloon. It is opaque on the ground. As it rises and expands, its skin becomes thinner and reflects and scatters light. They are used in quite large numbers in many places for routine observation because of their low cost. About 100,000 of these a year are flown in the United States, with most launches at scheduled times from airports and military installations. During their ascent up to 20,000 ft., the neoprene balloons are visible to the naked eye during the daytime, but once they attain an altitude of 20,000 ft. or higher they cannot be seen from the ground.

Super-pressure balloons

The other small balloons are the super-pressure "ghost" balloons. In general these have payloads of a few grams. The balloons are usually

spherical and size is a function of altitude; five feet in diameter at 20,000 ft., seven feet at 40,000 ft., ten feet at 60,000 ft. A few larger balloons have been flown at higher altitudes. Over 300 super-pressure balloons have been flown in the Southern Hemisphere. Several balloons have flown for over 300 days in the Southern Hemisphere with two balloons still flying which have been in the air for more than 11 mo. Not more than 20 long duration flights have been made in the Northern Hemisphere.

Polyethylene balloons

At launch polyethylene balloons are filled with a gas bubble varying from 20 - 70 ft. in diameter. Twenty feet of gas will lift a small balloon to 100,000 ft. A 70-ft. bubble is required to carry the Stratoscope II with a 7,000-lb. telescope. Scientists flying this type of balloon usually want to attain altitudes between 80,000 and 120,000 ft. to gather data on atmospheric radiation or composition. The "cosmic ray community" is the largest user of "ghost" balloons. The diameter of these balloons at altitude is anywhere from 60 - 250 ft. The 250-ft. size is for the Stratoscope II system. The largest balloons, those approximateing 300 ft., are designed for very high altitudes. The largest balloon that has been flown to date holds 2.6×10^7 cu. ft. of gas and is just under 400 ft. in diameter. There are a large number of 10,000,000 cu. ft. balloons being flown approximately half from Palestine, Tex. A few years ago the most common balloon was the 3,000,000 cu. ft. size.

2. Visibility

The relative visibility of a balloon depends on its type, size, material, time-of-day, and altitude. The human eye can usually detect a balloon against a bright sky background when the intercepted arc is 0.5 mil or greater. The radiosonde balloon is visible in daylight to a distance of two to four miles. During ascent, the "ghost" balloon is visible against the bright sky background at a distance of about two miles. At altitude the intercepted arc of "ghost" balloon varies

from between 0.2 - 0.6 mil. The polyethylene balloon provides a target of one to two mils at altitude.

The large polyethylene balloons absorb about 5% of sunlight; however, they scatter and reradiate as much as 20 - 30% of the incident light. This scattering is very much a function of angle. Polyethylene balloons are always visible at altitude during daylight hours when the sky is clear. It is often difficult to focus the eyes on the balloon, but once seen it is easy to relocate the balloon. The "ghost" balloon is not visible above 20,000 ft. during daylight hours.

Polyethylene balloons are shaped more like a pear than a sphere, although they always appear spherical from the ground to the naked eye. Glass fiber tapes affixed to the gore seams are used to strengthen polyethylene balloons carrying heavy payloads. Observed from the ground through a telescope, a shell effect gives a taped balloon a saucer-like appearance. The tape itself, which is the basic reflecting element, is quite shiny and reflects well. On very lightly loaded systems the balloons are tapeless; heavier loads require the glass fiber tapes. As seen through the telescope, then, the taped balloons appear much shinier and are distinguished by their scalloped appearance.

3. Derelicts and cutdown

Another phenomenon that might be witnessed by an observer during the day is what is known as the "cutting down" of a balloon. When the decision has been made to terminate a balloon's flight, the tracking aircraft will send a destruct signal to the balloon's control and command mechanism and a squib will fire. This will detach the payload and shatter the balloon. The payload is then tracked by the plane as it parachutes to the ground. Occasionally, however, the balloon will not shatter.

The shattering of a balloon during payload detachment is easily visible (especially in the late afternoon or early morning). However, the entire operation is not. The payload chute is only 60 ft. in diameter so that it is barely visible. The tracking plane which sends

the destruct signal may be 30 - 40 mi. away from the balloon. The "cutting down" of a balloon is usually accomplished one or two hours before sunset or just after dawn so that the pilot can visually track the parachute down. When the balloon does shatter, a large part of the balloon comes down in one piece as a flapping mass. There is little side motion or apparent hovering. Its speed of decent depends on how the balloon breaks up.

With improved balloon materials, there were a number of cases in 1966 where the balloon did not shatter but continued its ascent. Normally, if the balloon does not shatter, it should rise so fast after the shock that the gas does not escape rapidly enough to prevent bursting. Occasionally the balloon will begin to stretch, and if there is no weakness in it, the balloon could remain aloft at that higher altitude for four or five days. It might fly at 130,000 or 140,000 ft. until sunset at which time the gas will cool, reducing the volume by 5%. This causes the balloon to descend a few thousand feet. In daytime, at high altitudes the balloon's skin tends to run colder than the atmospheric temperature. As the balloon cools in the evening, it starts to descend because it has lost its volume. When it gets to approximately 60,000 - 70,000 ft., where the atmospheric temperatures are colder, the balloon is warmer than ambient temperature. It then picks up the 5% lost solar heat and continues to float along at this altitude until the next morning when it warms up and returns. to maximum altitude.

For example, a 1,000,000 cu. ft. balloon, launched in France came down in Montana in August 1966, after having remained aloft for 27 days. This balloon had been traveling at 60,000 to 100,000 ft.

4. Balloon motion

Actual balloon movement during the day is no more discernible than the movement of hands on a clock. At many times a balloon will appear to move if there are clouds in the sky just as a flagpole might seem to fall over when one is looking at it while lying on his back. The moon

demonstrates this same phenomenon when it seems to move across fields and jump fences while looked at from a moving automobile. Anytime there are clouds, a balloon may appear to move at extreme speed.

A small balloon observed in the first few thousand feet of ascent, of course, will be quite obviously moving. Our very large balloons climb at a rate of 700 - 1,000 ft/min; radiosonde balloons ascend at 1,000 - 1,200 ft/min. As these balloons reach higher altitudes, they could encounter strong wind shears (changes in velocity associated with changes in altitude) of the order of 30 knots/1,000 ft. Hence, velocity could change by as much as 30 knots in a minute, but even this would not make a large change in position. The angular movement would always be small over any one-minute period.

With respect to daylight sightings, pilots invariably estimate that balloons they see are considerably lower than their true height. For example, a pilot flying at 30,000 or 40,000 ft. will always report that the balloon is between 10,000 and 40,000 ft. above him. He will never say it is 100,000 ft. above him. The difficulty arises because no one conceives of a balloon 300 ft. in diameter. There is no depth to the balloon and no background which permits an estimate of either size or distance.

A frequent occurrence in Boulder, Colo., when searching for a balloon which has been recently launched, is to focus on the fluffy balls from a cottonwood tree floating 50 - 100 ft. above the observer. The cottonwood ball has been tracked on several occasions for two to three minutes before its motion convinced the observer that it was a one-inch cottonwood ball at 100 ft. and not a 10-ft. balloon at 10,000 ft.

5. Twilight effects

Just after sunset, a balloon may still be in sunlight. At this time the contrast becomes sharp and the balloon is clearly visible. A good bright balloon appears at least as bright as the brightest we ever see Venus when the planet is high in the sky : This "twilight effect" may continue from 20 min. to two hours.

At high altitudes we have another striking effect for the last few minutes before the sun sets at balloon altitude. This is caused by the sun reflecting off the balloon producing a rosy pink and later bright red color as the sun's rays pass through a hazy atmosphere and only the red end of the spectrum reaches the balloon. This has generated reports of fiery objects in the sky.

The neoprene balloons are also visible at twilight. An Australian scientist made experiments at NCAR for about a year using a new technique for measuring ozone. He flew a neoprene balloon with a little stopper attached which permitted the gas to escape and enabled the balloon to remain aloft for one or two hours at altitude instead of ascending and bursting. To make measurements of the reflectance of the sun on the balloon and determine the ozone concentration, he launched the balloons so that they would reach 100,000 ft. above the observing site just after sunset. These balloons were plainly visible about sunset, continued to become brighter and brighter, and then receded to a faint glow before disappearing.

6. <u>Lighted balloons</u>

Small rubber pilot balloons are still being used in many countries. For night soundings these two-foot diameter rubber balloons are tracked by small candles placed under the balloon. A single candle in a little holder has been used. The holder creates an even glow and keeps the candle from going out. The candle has been replaced in most countries by small battery-powered bulbs of approximately two candle power. Although the pilot balloon tracked by theodolite is no longer in common use in the U. S., a light is still used on radiosonde balloons at night to assist the observer to acquire the balloon, particularly if the night is dark and the trackers have had difficulty locking the radar set on the target. The blinking, bobbing light swaying under a pilot balloon or radiosonde balloon produces an exciting and attractive UFO. The FAA requires that large polyethylene scientific balloons carry lights when below 60,000 ft. at night. They can provide an awesome sight as they slowly ascend.

7. Frequency of flights

About 100 polyethylene balloons are flown each year from Palestine, Tex. San Angelo, Tex. has been an active launch area with as many as 100 - 200 per year. Chico, Calif., during the winter months has about ten flights, and Holloman AFB, N. M. (White Sands), has approximately 50 - 100 per year. Minneapolis remains still a center of balloon activities with 20 - 50 flights per year -- usually of small polyethylene balloons.

In addition, there are other field programs during the year that are undertaken by universities and manufacturers. Ten to 20 flights are made from Cardington, England each summer. A continuing flight program is conducted from Aire sur l'Adior, France. Australia, Russia, India, and Brazil have active flight programs using large polyethelene balloons.

About 100,000 of the small neoprene balloons are flown each year in the United States for routine observation. Radiosonde balloon flights constitute a vast undocumented area. They are generally sent up four times a day. Flight schedules are all based on Greenwich time. At some times of the year at some places in the country, the balloons will be going into altitude at twilight. There are approximately 100 sites in the United States that send up radiosondes four times a day. Records of launch time and location for these balloons are kept in Asheville, N. C.

A radiosonde balloon ascending to 100,000 ft. at twilight and then shattering can be the source of reports of a fiery object in the skies which disappears in a burst of flame.

8. Balloon UFOs

Two situations are illustrated that have produced UFO reports. In January 1964, a large balloon was flown from the Glen Canyon Dam area near Pago, Ariz. It was a 6,000,000 cu. ft. balloon with a light payload. The balloon, which was flying at 135,000 ft., had encountered extremely strong winds. About three hours after it reached altitude

it was decided to cut the balloon down. By this time the balloon was over Okla. It did not burst during payload detachment, but maintained its integrity and continued to ascend to 140,000 ft. When, just after sunset, it came over the East Coast at 140,000 ft., a number of pilot reports were received of a balloon sighted at 60,000 - 70,000 ft. Because it was at twilight on a very clear day, a number of people saw the balloon. This triggered a rash of flying saucer stories. For example, in Va. the people of a small town gathered a posse together to go out into a field to pick up the little green men. The sherrif attempted to halt them, but after a gun-waving encounter was forced to give up. The towns people then went out into the field and fortunately failed to find their little men.

At altitudes of 5,000 - 10,000 ft. we fly a different kind of "ghost" balloon. This cylinder-shaped balloon is approximately 20 ft. long and about two feet in diameter. We flew one of these from Boulder on 23 June 1965 at an altitude of 6,500 ft. We lost the balloon after a few hours. It went through some rather heavy showers, and seventeen days later over the Azores a silvery object like a long spear was sighted in the sky. At the same time as the silvery object was seen -- all of the clocks on the Azores stopped. Later investigation determined that an electrician short-circuited the island's clock power supply while he was working on a fuse box.

9. Conclusions

The public at large and even many scientists are unaware of the great number of balloon launchings that occur every year in all parts of the world. The majority of such launchings are for meteorological studies, but some relate to other atmospheric or astronomical research.

By far most of the balloons launched for whatever purpose go unobserved except by those directly interested in their performance. They perform their missions and are cutdown or burst unnoticed by the public. This is due to the fact that most launchings take place at times and under conditions which make observation -- and misidentification -- of them unlikely or impossible. As a result, when a balloon is observed

under unusual conditions by individuals not familiar with the kinds of devices described in this chapter it may be erroneously reported as an UFO.

Chapter 9

Instrumentation for UFO Searches

Frederick Ayer II

1. Introduction

Most of the thousands of existing reports of UFO phenomena are poor sources of information. They contain little or no data, are reports of hoaxes, or are the result of misidentification of familiar objects. Only a very small percentage of these reports provide concrete information from which any inferences can be drawn.

The need for instrumented observation of UFO phenomena arises from the fact that an observer's unaided senses are not reliable recorders of scientific data. Further, the ability of an observer to supply useful information is affected by his training, his state of mind at the time of the observation, and his suggestibility, both during and after the event. Accuracy requires instruments to measure precisely data such as angles, apparent or real velocities, distance, color, and luminance.

Even an observer with optimal training, objective state of mind, and minimal suggestibility is hard pressed when unassisted by instruments, to provide useful scientific information. This is especially true in the case of UFO phenomena, which are typically of short duration, occur in an unfamiliar environment, and lack points of reference from which reasonable inferences as to distance, size, and velocity can be drawn.

Even when instruments are available to him, the observer and the analyst of his report must be aware of a process inherent in any scientific inquiry; namely, the tendency of the investigator to look for evidence to support or discount a given hypothesis. In this state of mind, the investigator tends to disregard all data from his instruments that are irrelevant to his predetermined goal. An air traffic controller, for example, concentrates on radar echoes that he feels

quite certain are those that come from those aircraft for which he is responsible. A meteorologist focusses his attention on quite different data on the radar scope: thunderstorm, tornado, and frontal activity. The military observer pays less heed to natural phenomena and concentrates on data on the scope that might signify the approach of ballistic or orbiting bodies.

In other words, almost all investigative processes begin with a built-in "filter" designed to minimize whatever, for the investigator concerned, constitutes "noise." But one man's noise is frequently another man's data. The physicist interested in the elastic scattering cross-section of pi-mesons interacting with protons begins his analysis by setting up criteria that tend to eliminate all inelastic events.

This filtering process turned out to be at work when researchers in atmospheric physics examined the read-out of a scanning photometer, an instrument normally used in studies of airglow. The device scans a sector of the sky and records the result as a trace on paper tape. The zodiacal light and the Milky Way appear as broad humps; stars and planets as sharp spikes. An UFO would also appear as such a spike, but its motion would cause the spike to appear in different parts of the sky in successive scans.

Would the operator of the scanner notice such a trace? Or would he ignore it, along with the star and planet "noise"? Since his attention is focussed on the traces that indicate airglow, it seemed likely that he would fail to notice any trace attributable to an UFO.

This proved to be the case. Examination by project investigators of a zodiacal light photometer read-out made at the time of a visual sighting revealed four spikes in successive scans that could not be attributed to stars or planets. The personnel analyzing the data had ignored them. Geometric reconstruction of the object's path established that the photometer had recorded a ballistic missile in trajectory over the Pacific Ocean. Details are found in Section 8 of this chapter, "Haleakala II."

But even if the operator of an instrument fails to notice what, to him, is noise, another operator employing the same device for a

different purpose has access to all the recorded data and can therefore search for the specific information of interest to him. As demonstrated in the case of the scanning photometer, the instrument *can* be employed to provide a record of an UFO that can later be subjected to scientific analysis. Not all existing instruments, however, have adequate resolving power or other design features for effective searches for UFO phenomena.

Future studies of UFO phenomena should, in my judgment, be based upon information recorded by suitable instruments. This chapter will discuss existing instruments and instrument systems with special reference to their suitability for an UFO search. It will also suggest what instruments and instrument systems might be devised that would more readily yield suitable data for the study of UFO phenomena.

2. The All-Sky Camera

The all-sky camera was developed in order that permanent photographic records of the time of occurrence, intensity and location of auroral and airglow displays could be made automatically. During the International Geophysical Year, (1957-1958) 114 all-sky cameras were in operation at sites from near the North Pole to the South Pole.

The cameras are designed to photograph about 160° of the sky and to record angular distances from the zenith by means of lights. Photosensitive detectors switch the cameras on at dark and off at daylight. Exposures are short and can be set to any desired value. Local or Universal Time and length of exposure are recorded on each frame. Table 1 lists the salient points of the cameras of several participating countries. For further details see: Annals (1962) Gartlein (1947).

The film is examined by trained personnel and the data on auroral position and brightness in each of three areas, as a function of time, are entered on a five-line format called an "ascaplot." The three areas are the northern, zenith and southern. The northern and southern zones cover the regions lying between 60° and 80° from the zenith, and the zenith area takes in the whole of the sky between 60° and the zenith.

Table 1

Features of Some I. G. Y.

All-Sky Cameras

Country	Film width mm.	Number of exposures per hour	Exposure in seconds	Film Type	Time Accuracy
U.S.A.	16	60-80 alternating	10-20, 15,48	Eastman Kodak Tri-x, Ilford HP-3	± 10 sec. to ± 2 minutes
Canada	35	60	4-40 alterna- ting	Eastman Kodak Tri-x Pan.	± 3 sec. to ± 1 minute
Canada	16	60	30	Eastman Kodak Tri-x Neg.	± 1 minute
U.S.S.R.	35	12,60,120, 180 alternating	5,10,20 alterna- ting	High sensitivity Negative Pan.	± 2.5 sec.
Japan	16	240	13	High sensitivity Pan.	± 0.3 minutes
Argentina	16	60,48	20	Eastman Kodak Tri-x	± 1 minute

At a height of 100 km., the lowest altitude at which auroras generally exist, the camera covers a region of about 3° of latitude.

Most of the cameras record on 16 mm. film, and the diameter of the circular sky image is about 10 mm. Since the individual silver grains in the emulsion are of the order of 1μ (= 0.001 mm.) in diameter, an image less than 20μ is very poorly resolved. To produce a 20μ image, an object 100 km. distant would have to be no less than 600 meters in diameter. It is apparent that the resolution of such an instrument is not adequate for objects of more terrestrially common dimensions.

The sensitivity of the all-sky camera is also disappointingly low for purposes of UFO search. For instance, referring to point sources, Dr. Gerald M. Rothberg, in his report on one month's observation with one of these cameras, states that five miles is "roughly the maximum distance at which we can detect the landing lights on commercial airliners, as determined from photographs of planes. . ."

The sky-coverage of these instruments is very good, however, amounting to about 83% of a hemisphere of the same radius. However, each camera can sample only about 0.2% of the volume of sky 100 km. high over the continental United States, which amounts to about 9×10^8 km^3.

A thorough test of a 16 mm, U.S. all-sky camera was made by Dr. Rothberg during August 1967. (Case 27) The camera was operated for about 150 hours on seventeen nights. Exposures started at dusk and ended at dawn. The camera made one 40-sec. exposure per minute. The total number of frames taken was about 9,000 during a period when 106 local UFO sightings were reported. Rothberg states that

> ...continued at high frequency during the feasibility study, less than 12 of 9,000 all-sky camera exposures contained images not immediately identifiable. Only two of these coincided in time and azimuth with a sighting report. Study of one negative suggests that the image is either that of a meteor whose path was at or nearly at a right angle to the focal plane or that an emulsion defect or impurity is responsible for the image. The other negative's image was identified as a probable aircraft. (Case 27).

One UFO sighting was definitely recorded by the camera; the objects were three garment-bag balloons which were photographed repeatedly over a period of 15 min.

In appraising the value of the all-sky camera as the instrument to use in any follow-up investigations, Dr. Rothberg is "less than enthusiastic about (their) use" for an UFO search.

Put very simply, a camera designed for the observation of airglow and auroral phenomena, both of which are large, amorphous luminous regions, does not have the resolution necessary for investigating phenomena such as fireballs, ball lightning, tornadoes, or UFOs.

3. The Prairie Network

Instrumented meteor astronomy is a comparatively young field dating back not much before 1936 when the Harvard Meteor Project began. Determination of mass distributions, size and composition has been difficult because results have to be arrived at by inference only instead of from studies of samples collected in the field.

Current theory holds that meteors originate from two sources: comets and asteroids. It is thought that meteors which survive long enough in our atmosphere to reach the surface are asteroidal in origin. From spectroscopic evidence it appears as if comets were composed of solid particles - "dust" - weakly bound by material which can exist in solid form only at very low temperatures. Only the dust can exist for an appreciable time in the solar system, and it is these solids which appear as cometary meteoroids. As a matter of interest, this does not preclude the deep penetration of our atmosphere by large cometary fragments. The Tunguska Meteor of 1908 is thought to have been such a fragment, and the devastating effect of this encounter is still visible today (Krinov, 1963).

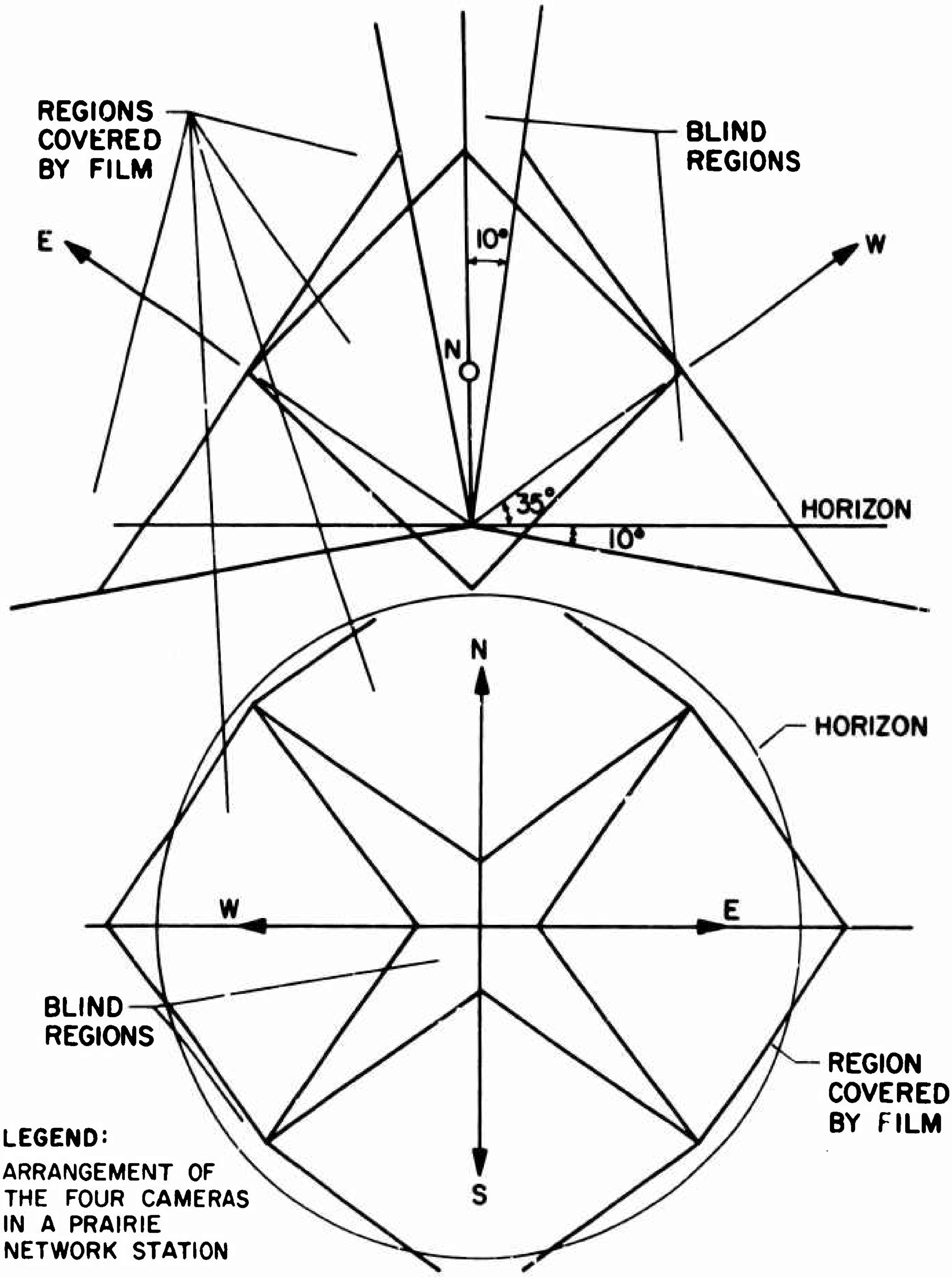
Almost all meteorites in museum collections were found accidentally and the time of landing for about half of them is unknown. Seeking to increase the recovery rate and to pinpoint the time of arrival, the Smithsonian Institution began to design the Prairie Network in

the early 1960s (McCrosky, 1965) in such a way as to increase the area coverage over that of the Harvard Project and to improve the probability of observing large, bright objects. Between 1936 and 1963 four technical advances proved particularly important in the basic design of the system: the Super-Schmidt camera, much faster photographic emulsions, radar, and the image orthicon. The Super-Schmidt and high-speed film were originally used in an effort to determine the trajectories of faint meteors having initial masses of $\sim 10^{-2}$ gm. The radar and image orthicon have been combined into a system for the study of meteors which are fainter than the Super-Schmidts were capable of detecting, and which are presumed to be of cometary origin. A grant from NASA established the network and the first prototype photographic station went into operation at Havana, Ill. in March 1963. About a year later, the network first functioned when ten stations began working reliably.

The complete network now consists of 16 stations of four cameras each, located at the apices of a set of nesting equilateral triangles having a separation of 225 km. Each of the four cameras is aligned with a cardinal point of the compass with the diagonal of its 9.5 sq. in. film oriented vertically. The optical axis of the camera is elevated at an angle of 35° to the horizon, but as the effective field of the present lenses is ~100° one corner of the film will photograph ~10° below the horizon and the extreme of the opposite corner falls short of covering the zenith by ~10° (See Fig. 1) As a result, there are five blind spots, one vertical and the other four at true compass bearings of 45°, 135°, 225° and 315°, amounting to about 20% of the total hemisphere. All 16 interlocking stations cover a total impact area of 1,500,000 km^2.

The Super-Schmidts are capable of recording stars with a photographic magnitude of as low as $M_{pg} \approx +3$, but the network cameras have considerably lower sensitivity, computed at $M_{pg} = -3$.

The angular velocity of the meteorite is determined by interrupting the streak of its path on the film by means of a shutter that


REGIONS COVERED BY FILM
BLIND REGIONS
E
W
10°
N
35°
HORIZON
10°
N
HORIZON
W
E
BLIND REGIONS
REGION COVERED BY FILM
S
LEGEND:
ARRANGEMENT OF THE FOUR CAMERAS IN A PRAIRIE NETWORK STATION

runs continuously. The shutter motion is interrupted at regular intervals in order to produce a timing code that indicates time in reference to a clock face photographed on each frame. This permits fixing the time of passage with respect to the exposure interval.

The standard exposure is three hours so that three to four frames are produced each night. Operation of the camera is controlled by photosensitive switches that turn the system on at twilight and off at dawn. To prevent fogging by moonlight or other bright sky conditions, each camera is equipped with both a neutral density filter and a diaphragm activated by a photometer.

Other features insure the proper exposure and recording of time intervals of meteors having a photographic magnitude greater than $M_{pg} = -6$.

Stellar magnitudes are stated on a logarithmic scale. A difference of five magnitudes corresponds to a ratio of brightness of 100. Because the astronomers traditionally have referred to a bright star as being of "the first magnitude," and less bright stars as being "second magnitude" or "third magnitude" stars, the sign given to a magnitude is inverse to its brightness. An object of M_v -1 is, by this convention, 100 times brighter than an object of M_v +4 (a difference of five magnitudes). Magnitudes of some familiar heavenly bodies are: sun -26.72; full moon $\sim$-12; Venus -3.2 to -4.3; Vega +0.1; Polaris +2.1. The faintest magnitude visible to the normal, unaided human eye is about +6.

Photographic (M_{pg}) and radar (M_{rad}) magnitudes are related to visual magnitudes by coefficients which are functions of the wavelength of the radiation as well as the characteristics of the detector.

Although a meteor may be recorded by more than two cameras or stations, only two views are necessary to determine altitude, velocity, and azimuth. The two best views are those in which the line joining them is the most nearly perpendicular to the trajectory. Such stereo-pairs will detect meteors at altitudes of 40-120 km. If the measurements indicate that the meteor may land in a region relatively

accessible to network personnel, a third view of the trajectory, downstream from the first pair, and where the meteor has fallen to an altitude of between 10 and 40 km., is then measured to determine the rate of momentum loss from which the impact ellipse is computed.

Exposed film from one-half of the stations is collected every two weeks and scanned at field headquarters in Lincoln, Neb. The rate of acquisition of film is ~500 multi-station and ~500 single-station meteors per year. Frames with meteors from one station are cut out of the film strip and a search is made for views of the same event taken at other stations. The assembled events are then sent to Cambridge, Mass. for measurement. It is necessary to measure the length of every interval on the meteor track produced by the shutter, the positions of about forty stars, and to make densitometric measurements of the trace.

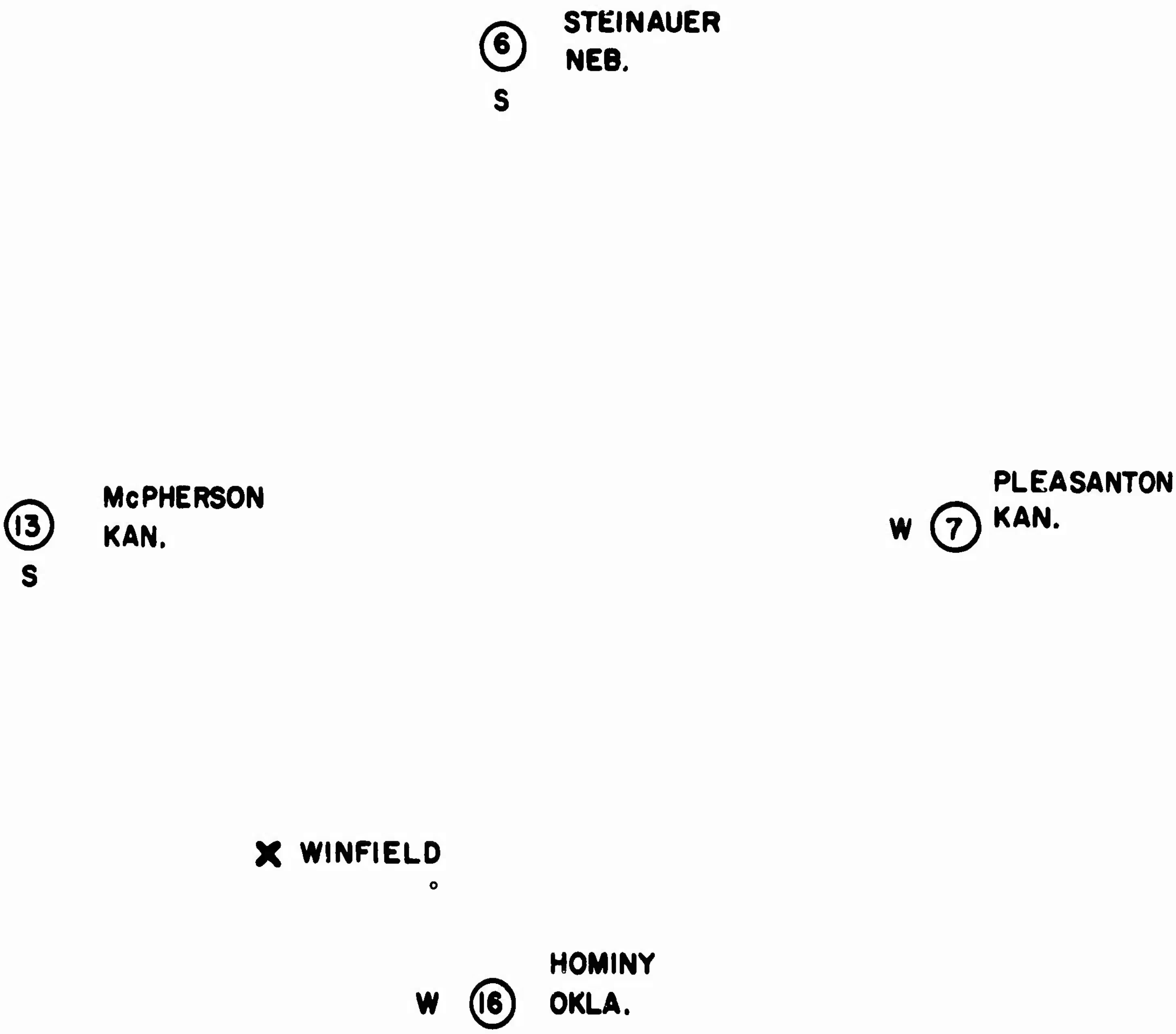
One of the most important functions of the network is to facilitate recovery of meteoritic material. The network's design is adequate to provide an "impact error" of 100 meters for the "best determined objects." But such accuracy fails to guarantee recovery because the object of search is nearly indistinguishable from the more common field stones. One recent search occupying 150 man-days resulted in no recovery. Since the start of the project some 500 man-days of search have yielded no recoveries.

In contrast, the Canadian "network," which was not yet in operation by June 1968, has already recovered at least one meteor by careful and extensive interrogations of persons who had witnessed meteor falls. Similarly, in Czechoslovakia, four pieces, out of the many which make up the Pribram meteor, were recovered before the impact point had been determined from data obtained by a simple two-staiton system not designed for this purpose.

4. Evaluation of the Prairie Network

Colorado project scientists attempted to evaluate the usefulness of the Prairie Network as an instrumented system for UFO searches. A list of UFO sightings dating back to 1965 that occurred within the network limits was presented to the supervisor of the field headquarters in Lincoln, Neb. He was requested to produce those plates which might conceivably have been able to photograph the objects which gave rise to the sightings. Information supplied to the supervisor was deliberately limited to case number, year, month, day, time, city, duration, direction, and location. Duration of the sighting was given in minutes. Direction in the sighting reports referred either to the direction in which the observer was looking, or the direction of motion of the object. Location was specified by the coordinates of an atlas. Presenting the information in this form avoided biases based on preconceptions and placed more emphasis on the immediate environs of the sighting point. The assumption that an UFO was in the immediate neighborhood of the sighting was made so as to combat any tendency to attribute sightings to distant objects, that is, to astronomical bodies.

A map was prepared for each case (see Fig. 2) and each film scanned for exceptionally bright objects and planes or satellites. Tracks of bright meteors were never seen because the films on which they appeared had been sent to Cambridge, but the azimuth, elevation, and trajectory of these meteors were available and correlated with the sighting report. Angular positions of bright objects were roughly determined by means of a template.


6 STEINAUER NEB.
S
13 McPHERSON KAN.
S
W 7 PLEASANTON KAN.
WINFIELD
W 16 HOMINY OKLA.

The following criteria were applied to the reports and to the films:

Not operating (NO): cameras do not operate before dusk or after dawn and they sometimes malfunction or run out of film.

Meteor (M): a fireball with a known trajectory computed by its film tracks at several stations.

Overcast (O): this applied to cases where two nearby stations were so overcast that no star images showed, and where there was little information on films from more distant stations.

No information (NI): this classification was used when the report failed to state the direction in which the observer was looking or the direction in which the object was moving, or both.

No conclusion (NC): the report information was so fragmentary that no correlation between the objects on the photograph and those reported, was possible, or the films gave no information which could confirm that an object was seen.

Inconclusive identification (II): if the photographic evidence showed the presence of a body which could have been responsible for the sighting with a fair degree of probability, the case was called inconclusively identified.

Conclusive identification (CI): when description in the visual report was confirmed with a high degree of probability in all characteristics, the case was considered to be conclusively identified.

The following rules were adopted:

a) All NI cases became NC
b) No NO cases were labelled NC
c) Some O cases were classified NC

Of 114 cases, two were identified as meteors, one conclusively and one inconclusively, four cases received conclusive and 14 inconclusive identifications. Of the remaining cases 80 were classified NC; and 14, NI or NI combined with NO and O.

The sighting identified conclusively as a meteor was made by a couple who were driving north on Highway 281, six miles north of Great Bend, Kans., at 2200 CST. They reported that they saw ". . . a flash or burst of fireworks above car, not unlike the usual Fourth of July fireworks, except that this was much larger and much higher. The fireworks or sparkles were varicolored and out of them emerged a disc-like object about the size of an ordinary wash tub. The object was as red as fire, but it appeared solid with a very definite, sharp edge . . . . and traveling at a tremendous speed. Its direction was north-northeast and in a straight line. . . . It did not require more than five seconds to reach a distance that made it invisible . . ."

Two phrases in this statement needed clarification: "above us" and "its direction was north-northeast." The observer explained that "above us meant through the upper part of the windshield." He said that his (and his wife's) attention was called to the object by the flash of the burst, which they saw just to the west of north, and it vanished while still slightly west of north. He insisted that the object was traveling north-northwest, explaining the correction by saying that he often confused west with east. He was therefore certain that it could not have been on the NW to SE course determined from the photographic data, and that it was not a meteor because it was rising, not falling. Questioned as to the time, he said that 10:00 P.M. was approximate and that the duration of the sighting was short, probably less than the five seconds referred to.

Six stations of the Prairie Network photographed a meteor at about 10:10 P.M., determined that it passed over Republican City, Neb. at an altitude of some 50 km., and predicted that its point of impact was near Downs, Kans. Republican City lies a few degrees west of north from the sighting point at a distance of about 177 km., and Downs

an equal number of degrees east of north at a distance of about 116 km. Assuming a mean distance of 145 km., the observer saw the meteor at an elevation of approximately 19°. The elevation of the top of a windshield of an American two-door sedan from the eye level of a man of average height is about 25° or less.

The observer's impression was that the object was rising. This would be expected if it were approaching him at a constant altitude. His strong feeling that it was on a northerly course, and therefore receding, is explained by recalling the very short time during which he saw it.

Considering the general agreement as to time, elevation and region of viewing, the probability is high that the object seen was the meteor photographed.

The second case was labeled inconclusive because, in spite of the paucity of information available about it, there was a relatively close agreement between the time of the sighting (0001 CST, 26 January 1967) and the time of a meteor recorded on three network stations (2341:51 CST, 25 January 1967). The discrepancy of only 18 minutes leads to a probable identification of the sighting as the meteor, but the identification cannot be made conclusive.

A striking example of the lack of correlation that can occur between a familiar ob ect and the interpretation of a sighting is related in the case where a large, helmet-shaped, luminous body appeared overhead from behind a cliff. The observer was driving west. He reported that the object stayed nearly overhead for 45 min. until it disappeared behind a hill to the southwest at an altitude of about 40°.

Network photographs show the moon moving from 245° to 270° at a starting elevation of 85° dropping to 45°. Stars and a plane also appeared on the film, but their positions did not tally with the report.

Neither the observer nor the Air Force interviewer mentioned that the moon was visible, but the conclusion appears to be inescapable that the object seen was the moon. A summary of the results of this

study is presented in Table 2 .

Bearing in mind that Prairie Network optics and geometry were designed to detect bright astronomical objects at high angular velocities, it is not surprising that 100% of the conclusive and 67% of the inconclusive identifications relate to astronomical objects. In fact, any future investigation utilizing the network should guard against a possible bias arising from its design features.

The network's identification of 18% of all sightings with a fair degree of probability, does not constitute as poor a performance as might be thought since 34% could not be recorded because of overcast and 43% were so deficient in information that, even if an object had been recorded by the film it would have been impossible to correlate it with the sighting.

5. The Tombaugh Survey

In 1923, Dr. W.H. Pickering called attention to the possibility that undiscovered small natural earth satellites might exist. In 1952, after a long period of searching for trans-neptunic planets and "lost" asteroids, during which the planet Pluto was found, Dr. Clyde W. Tombaugh began a search for small satellites which might be in circular geocentric orbits having radii between 5,000 and 26,000 mi.

In searching for small, high-velocity bodies having a luminance close to the photographic threshold, it is essential to avoid "trailing"; that is, the image must be kept stationary with respect to the film. For example, if a star image 0.04 mm. in diameter trails over the emulsion for a distance of 10 mm., its brightness at any point will be diminished in the ratio 0.04/10.0 = 1/250 times. The resulting trail image may be below the film's threshold. Therefore, Dr. Tombaugh's experimental method was based on searching the surfaces of a large number of spherical shells, each concentric with the earth. The angular velocity of the search in each shell was made equal to the angular velocity a body moving in the gravitational field of the earth would have at a geocentric distance equal to the radius of that shell. (Tombaugh, 1959).

Table 2

Prairie Network Study

Summary of Sighting Identifications

State	O	NI	NO	total	NC	M	CI	II	conclusively astronomical	inconclusively astronomical
S. Dak	0	0	0	5	2		0	3		2
Neb.	4	6	0	10	8		1		1	
Kans.	3	9	1	14	9	1	0	3		1
Mo.	10	7	2	27	17	1	3	3	3	2
Iowa	3	2	1	11	8		0	2		
Ill.	11	16	5	33	27		0	1		1
Okla	3	3	3	14	9		0	2		2
Total	34	43	12	114	80	2	4	14	4	8
% Total	30	38	11		70	2	4	12	100	67

The minimizing of trailing permitted the recording of images down to the M_{pg} = +15 in a 2 min. exposure. A dark rock, four feet in diameter, having a reflectivity equal to that of the moon, at a geocentric distance of 26,200 miles, would produce an image of this photographic magnitude.

The project was terminated at the end of June 1956. The number of concentric shells searched was over 100, resulting in a collection of 13,450 photographs. A few dozen possible natural satellite images having photographic magnitudes lying between +16 and +14 were found and attempts were made to recapture them by repeatedly photographing the shells in which they occurred, but with no success. The conclusion is that these images were either film defects, very small asteroids in elliptical orbits around the sun, or natural satellites in elliptical, rather than circular, orbits around the earth.

As a by-product of this project, a search for moon satellites was made during the lunar eclipse of November 1956. Three telescopes, monitored by a sky photometer, produced a total of 25 plates, recording point images down to about M_{pg} = +17. Some 500 candidates were found in the region between the moon's surface and a lunicentric distance of 37,000 miles, but none survived a detailed analysis.

A program of visual observation for nearby objects at very low latitudes began at the end of 1955 and continued through 1958. The equatorial plane, at distances between 600 and 2,500 miles from the surface of the earth, was searched with a twelve inch Newtonian reflecting telescope and 10 X 80 binoculars. The telescope had a limiting visual magnitude of +11 at 100 miles and + 13 at 2,400 miles, while the binoculars could detect objects of M_v = +8 at 100 miles and of M_v = +9 at 2,800 miles. No satellites were seen. In the words of the report:

> It is most unlikely that any objects larger than [two feet in diameter at an altitude of 100 miles or twenty feet at 2,500 miles as seen by binoculars, and several inches at 100 miles or three feet at 2,500 miles as seen

by the telescope] existed . . . . during 1956, or that any natural objects have since entered these regions.

The method used by Dr. Tombaugh, while admirably suited to orbiting bodies, is not appropriate for the observation of aerial phenomena that are not constrained in circular orbits. If their distances from the cameras were large they would not be detected due to the effect of trailing. For this reason a search on satellite survey films for reported UFOs was not attempted.

6. Scanning Photometers

Photometry of the night sky is carried out by means of photomultipliers which sweep out circles parallel to the horizon (almucantars) at various zenith angles Z(Z = 90°-altitude). Photometers used in airglow studies have a 5° field and sweep at the rate of 10°/sec horizontally and 5°/sec vertically. A "sky survey" consists in making 360° sweeps at each of six zenith angles as follows: scanning clockwise at Z = 80° at the rate of 10°/sec, counter-clockwise at Z = 75° at 5°/sec and repeating the process at the same rate at Z = 70°, 60°, 40°, and 0°. A survey requires 4.1 min. Often a series of surveys is made using different filters depending on the nature of the investigation.

The output of the instrument consists of pulses, the amplitude of which is proportional to the intensity of the light sensed by the photometer. In older models the output is recorded analogically by a pen on paper tape. Since the distance along the length ("x" axis) of the tape is proportional to the time of the scan, it is therefore an indicator of the azimuth and zenith angle of the light source represented by the pulse. Data are analysed by measuring the height of pulses of interest ("y" axis) and determining their azimuth at each zenith angle. This measurement is done manually or in the new model, by recording the coordinates directly on machine-readable magnetic tape.

The angular size of the field, sweep rate, and other quantities differ depending on the use to which the instrument will be put. A zodiacal light photometer, for example, has a narrorwer field, 3°, scans at about 2°/sec and sweeps out almucantars at much smaller zenith distances, that is at altitudes much closer to the zenith.

Bodies brighter than $M_V = +3$ can readily be identified by their angular coordinates coupled with pulse height which is a measure of their magnitude. In practice, however, identification is rarely carried out because investigators of airglow and zodiacal light are interested in diffuse light phenomena rather than in single bright objects.

The sky coverage of the photometers is large since they can be made to scan an entire hemisphere as in the case of the all-sky cameras. The fact that they do not do so in the same short period of time as the cameras is not very important since at large distances the linear sweep speed approaches the velocity of light. Because their observations are made over a longer period of time and their angular data is recorded over a very much larger area, they have a greater resolution; azimuth and altitude are presented more accurately and the direction of motion is non-ambiguous.

Colorado project scientists thoroughly searched two such photometer sky surveys. The first search was made on an airglow survey chosen at random and the results are summarized in section 7 of this chapter. The second search was prompted by a visual sighting by three trained persons of a bright object in retrograde (E to W) motion during the operation of a zodiacal light photometer.

Scanning photometers can also sense different colors on separate surveys. The instrument's ability to measure the degree and direction of polarization can also aid in determining whether the object is self-luminous or its light is reflected. For these reasons, and because of their relatively extensive sky coverage, scanning

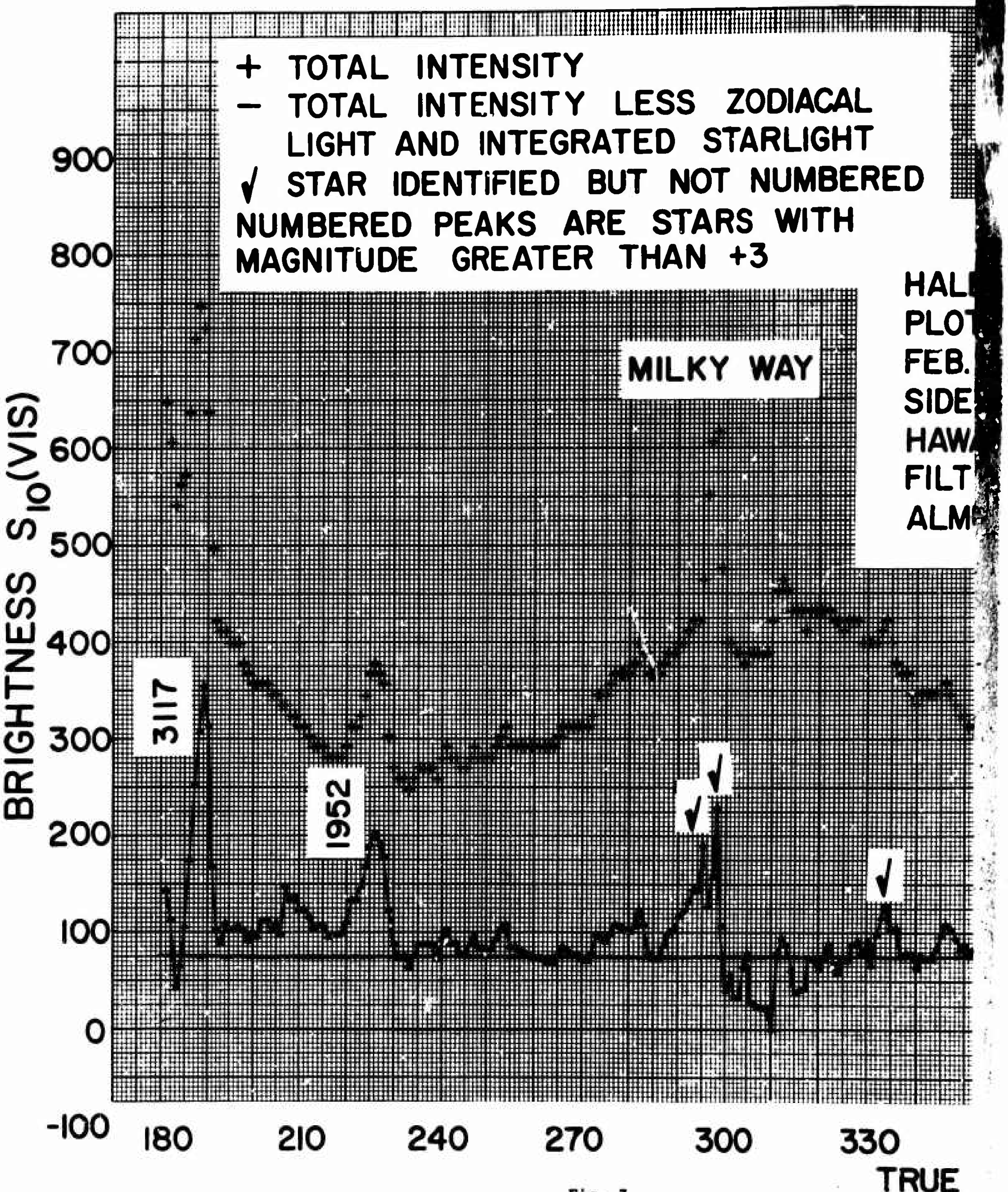
photometers can be considered useful intruments in the conduct of UFO searches.

7. Haleakala I

A search was made of the taped output of an airglow photometer survey recorded around midnight, Hawaiian Standard Time (HST), 11-12 February 1966 in order to see if all bright objects could be identified as stars or planets. This survey was chosen at random from a sample of surveys made under particularly good conditions, that is, on nights during the dark of the moon with the minimum interference from clouds. The taped data, consisting of brightness as a function of azimuth, was plotted by machine in two ways, the first showing the raw data which included light from all sources, and the second, the raw data from which the background of zodiacal light, Milky Way and integrated starlight had been subtracted. On both plots, individual stars and planets stand out as narrow pulses, their height being proportional to their apparent magnitudes. The brightness is measured in terms of the number of 10th visual magnitude stars per square degree of sky, that is, in "S_{10}(vis)" units.

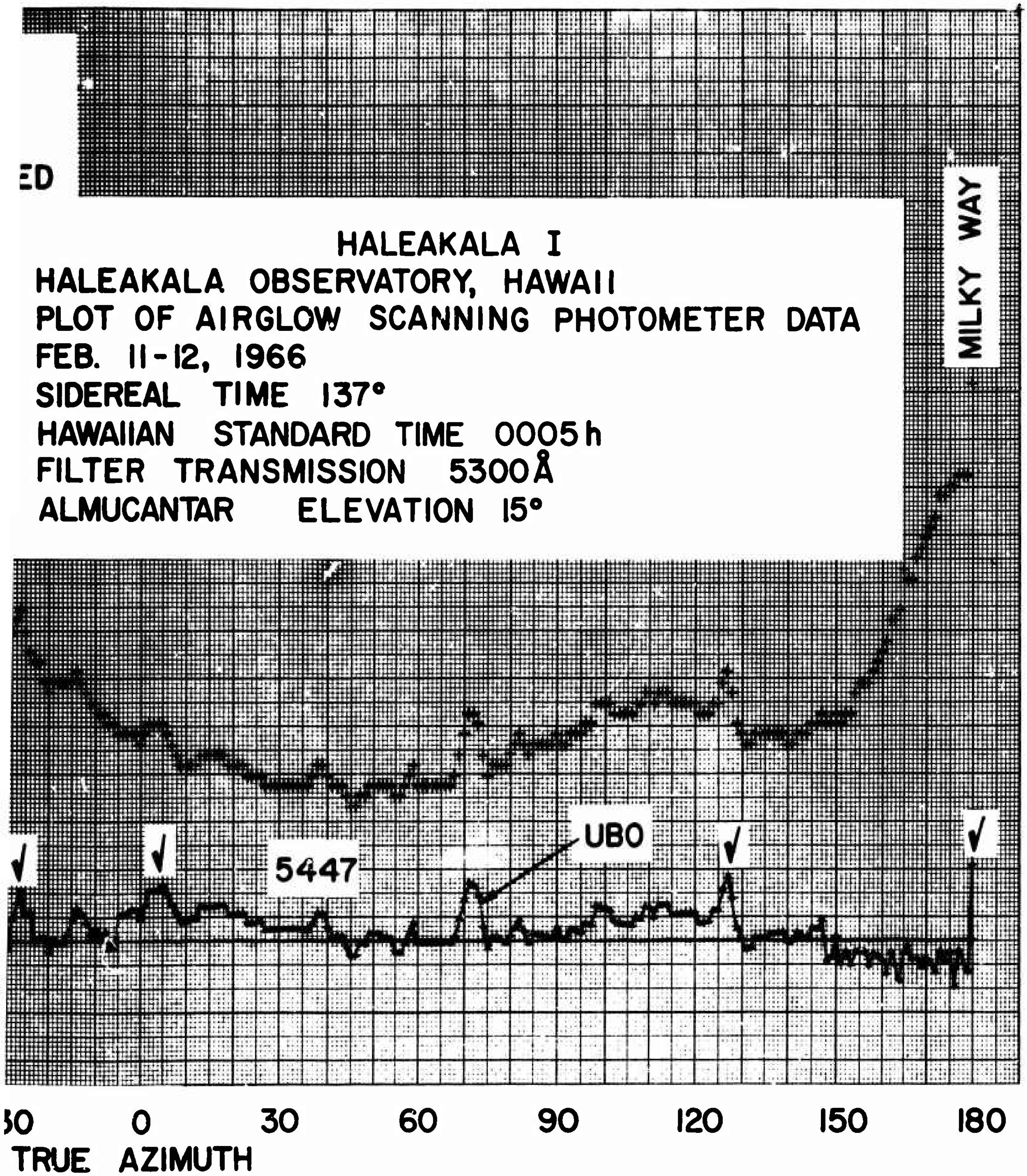
The observations of that night were made through three filters successively: 6300 $\pm$ 5 Å, 5577 $\pm$ 5 Å and 5300 $\pm$ 25 Å. As each survey through each filter requires about four minutes, successive sweeps at the same zenith distance through the same filter occur at ~15 min. intervals, and one sweep at, say Z = 80°, will be followed by a sweep at Z = 75° about 36 seconds later and repeated at the same altitude about 15.5 min. later.

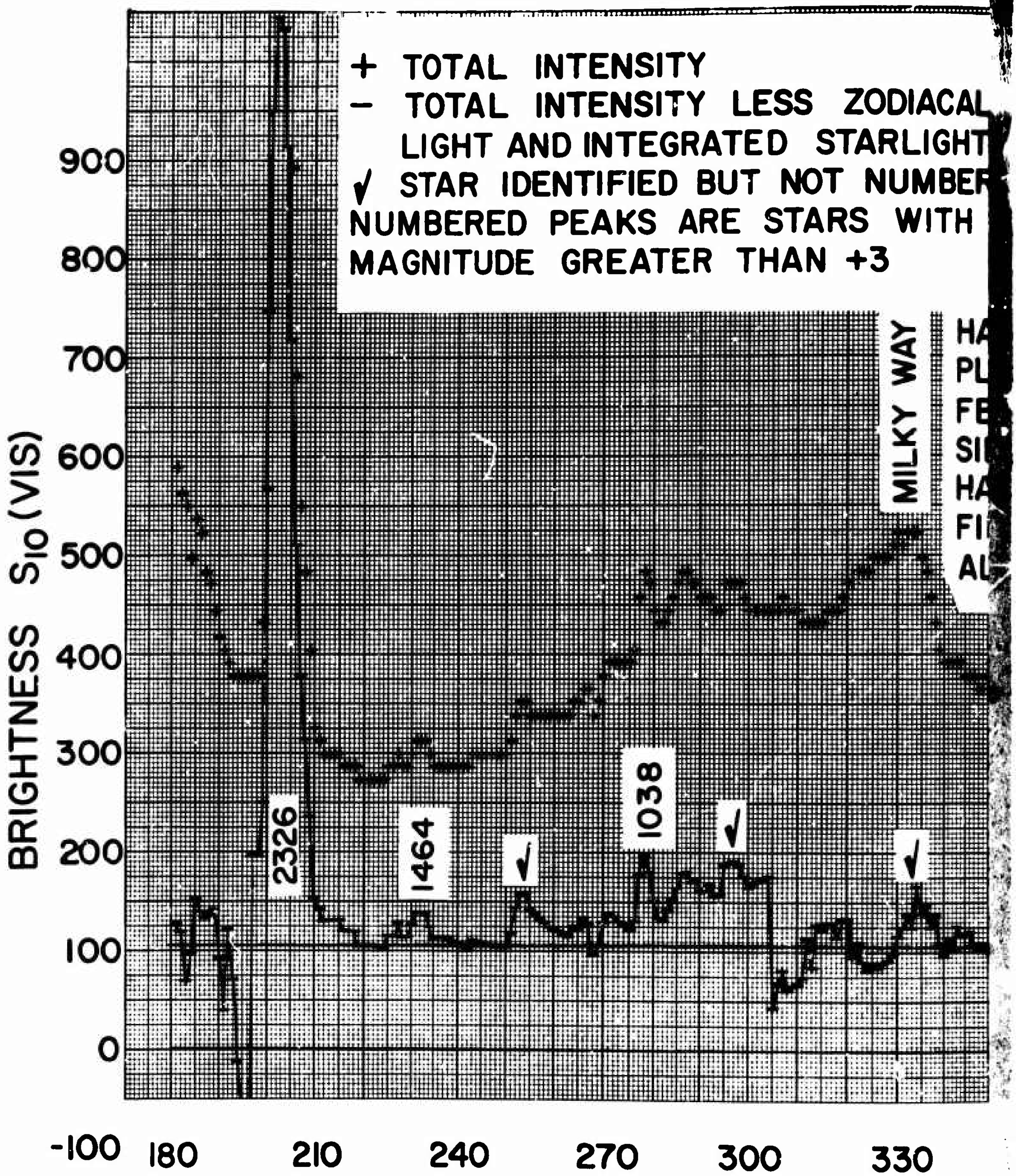
No stars or planets showed up in the surveys through the 6300 Å and 5577 Å filters, but probably because of its broader band-pass, many more appeared when the 5300 Å filter was used. In this survey, all star pulses greater than M_v = +3 were accounted for by reference to a star atlas, except for two. These have been designated as Unidentified Bright Objects (UBO), having the coordinates given (see Figs. 3 and 4) below (see also Figs. 5 and 6).



+ TOTAL INTENSITY
— TOTAL INTENSITY LESS ZODIACAL LIGHT AND INTEGRATED STARLIGHT
√ STAR IDENTIFIED BUT NOT NUMBERED
NUMBERED PEAKS ARE STARS WITH MAGNITUDE GREATER THAN +3
HAL
PLOT
FEB.
SIDE
HAWA
FILT
ALM
MILKY WAY
3117
1952
BRIGHTNESS S_{10}(VIS)
900
800
700
600
500
400
300
200
100
0
-100
180
210
240
270
300
330
TRUE

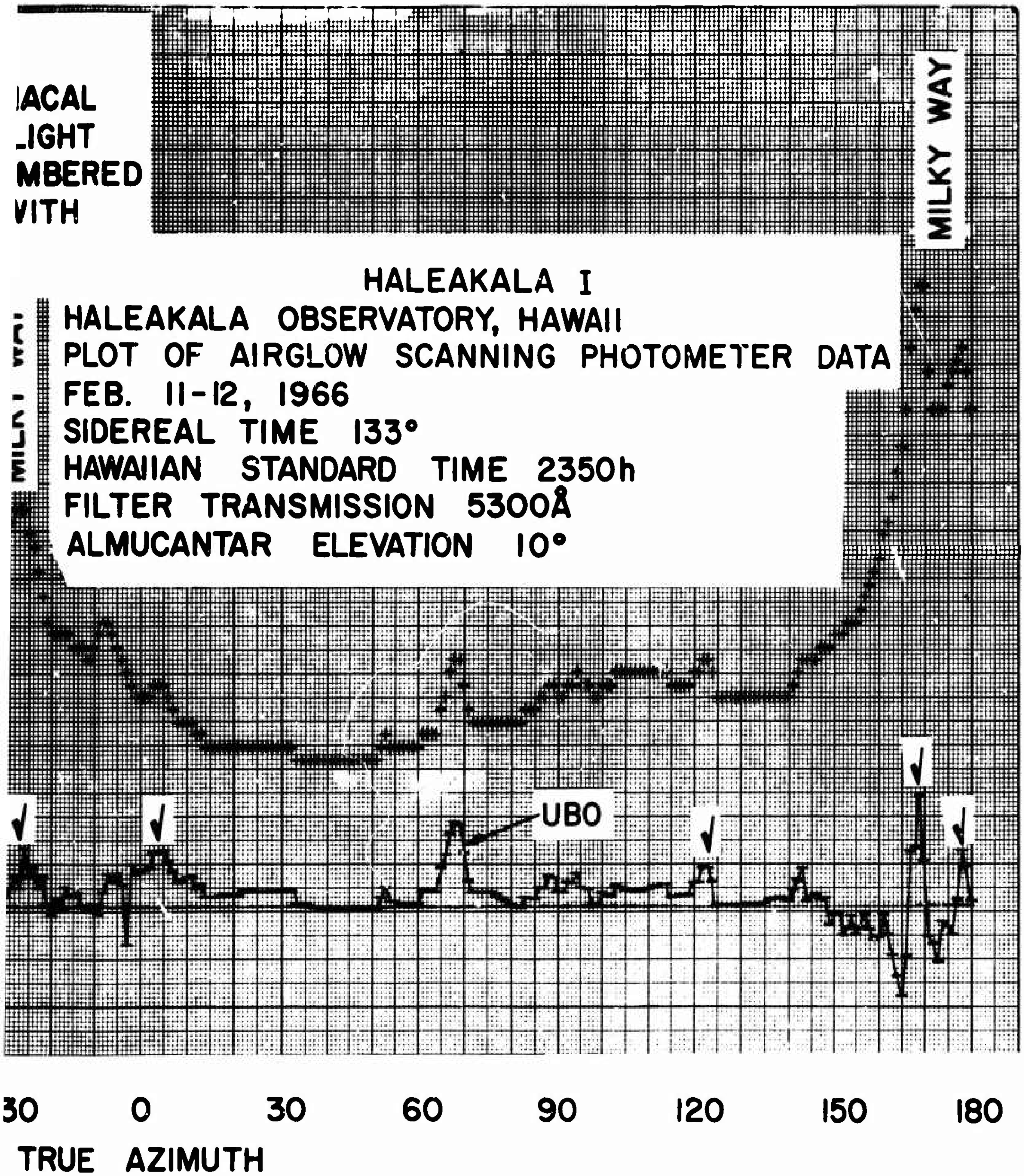
Fig. 3


ED
HALEAKALA I
HALEAKALA OBSERVATORY, HAWAII
PLOT OF AIRGLOW SCANNING PHOTOMETER DATA
FEB. 11-12, 1966
SIDEREAL TIME 137°
HAWAIIAN STANDARD TIME 0005h
FILTER TRANSMISSION 5300Å
ALMUCANTAR ELEVATION 15°
MILKY WAY
UBO
5447
30 0 30 60 90 120 150 180
TRUE AZIMUTH



+ TOTAL INTENSITY
− TOTAL INTENSITY LESS ZODIACAL LIGHT AND INTEGRATED STARLIGHT
√ STAR IDENTIFIED BUT NOT NUMBER
NUMBERED PEAKS ARE STARS WITH MAGNITUDE GREATER THAN +3
MILKY WAY
BRIGHTNESS S_{10} (VIS)
900
800
700
600
500
400
300
200
100
0
-100
180
210
240
270
300
330
TRUE
2326
1464
1038

Fig. 4



ACAL
IGHT
MBERED
VITH
MILKY WAY
HALEAKALA I
HALEAKALA OBSERVATORY, HAWAII
PLOT OF AIRGLOW SCANNING PHOTOMETER DATA
FEB. 11-12, 1966
SIDEREAL TIME 133°
HAWAIIAN STANDARD TIME 2350h
FILTER TRANSMISSION 5300Å
ALMUCANTAR ELEVATION 10°
UBO
30
0
30
60
90
120
150
180
TRUE AZIMUTH

Angle Z	HST	Azimuth
80°	2350	68°T
75°	0005	72°T

The pulses were separated by 4° in azimuth and 5° in altitude. The azimuthal error in this photometer can be as great as ± 4°. Since the field is 5° and the point source can be sensed equally well over almost the entire width of the field, the altitude uncertainty may be ± 5°.

From the recorded values of the angles, if the two pulses were made by one body, it moved an angular distance of

$$\phi = \sqrt{4^2+5^2} = 6.5° \equiv 0.1134 \text{ rad}$$

If the errors are in phase, then, maximally:

$$\phi_{max} = \sqrt{(4+4)^2 + (5+5)^2} = 12.8° \equiv 0.2240 \text{ rad}$$

and minimally

$$\phi_{min} = \sqrt{(4-4)^2 + (5-5)^2} = 0°$$

The fact that the UBO appeared on only two sweeps out of many surveys may be interpreted to mean that it vanished in the shadow of the earth at $Z \approx 75°$. This situation is shown two-dimensionally in Figs. 3 and 4.

In Fig. 5, which is a view of the earth, looking toward the southern hemisphere, Haleakala (21°N) lies on the earth-sun line at 2400 HST, and the edge of the earth's shadow is parallel to it. In the first approximation, the distance d from Haleakala to the shadow line in an easterly direction is

$$d \sim R = 6371 \text{ km.}$$

and

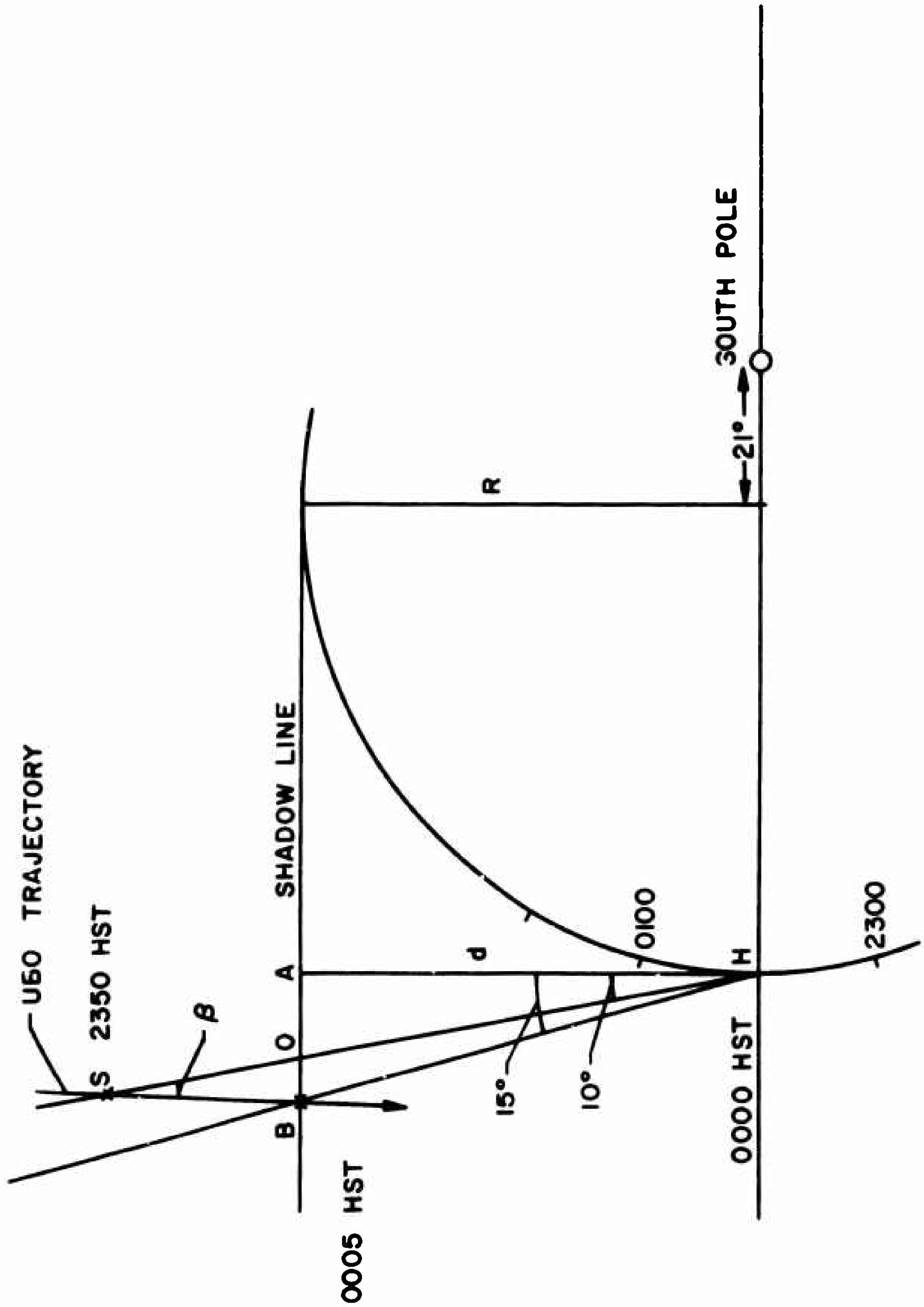
$$OH = d/\cos 10° = 6469 \text{ km.}$$

The nominal, maximum and minimum distances travelled by the object are:

$$OB_{nom} = 6469 \times 0.1134 = 734 \text{ km.}$$

$$OB_{max} = 6469 \times 0.2240 = 1449 \text{ km.}$$

$$OB_{min} = 0 \text{ km.}$$


UFO TRAJECTORY
2350 HST
S
β
B
O
A
d
SHADOW LINE
R
15°
10°
0100
H
2300
0000 HST
0005 HST
21°
SOUTH POLE

in 15 min., for a velocity of:

$$V_{nom} = 48.9 \text{ km/min}$$

$$V_{max} = 96.6 \text{ km/min}$$

$$V_{min} = 0 \text{ km/min}$$

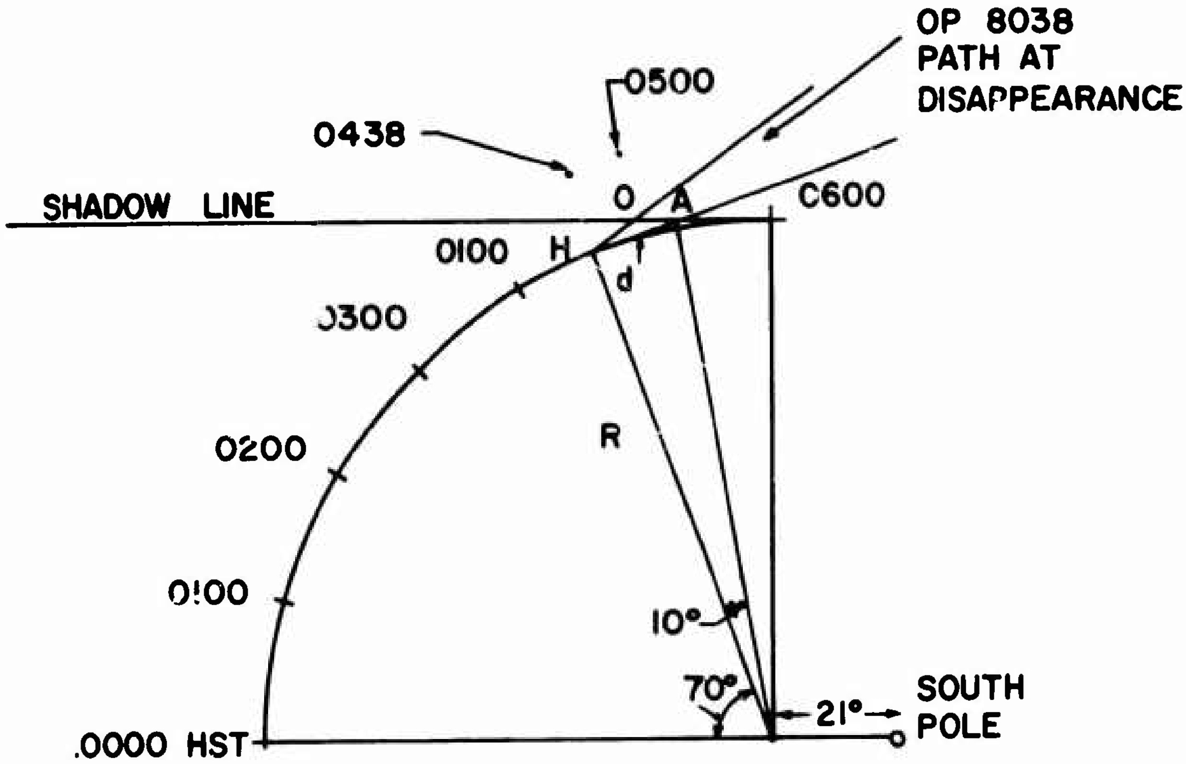
These velocities should be compared with those of the UBO in Haleakala II, that is, ~ 142 mi/min ≡ 228 km/min. If the UBO was in orbit, the distance OB is the projection of its path SB making an angle β with the line of sight. Assuming that the velocity in Haleakala II is typical, then

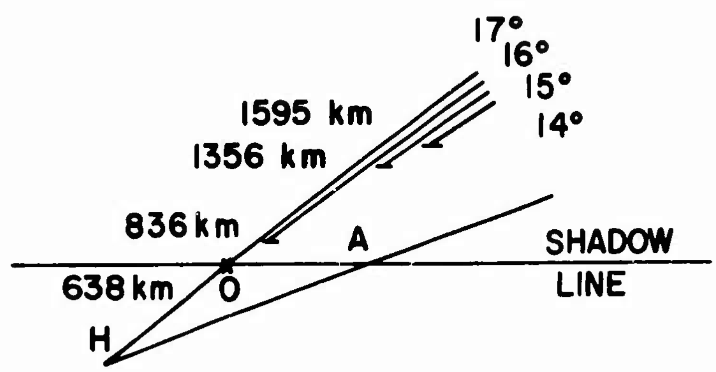
$$\text{Sin}\beta_{nom} \sim \frac{48.9}{228} \sim 0.214$$

$$\beta_{nom} \sim 12°$$

and the object was in a highly elliptical orbit. Alternatively, the distance OB might have been the projection of the apogee of the ballistic trajectory of a body launched in a retrograde direction.

Investigation showed that no sub-orbital missiles were launched from Vandenberg AFB or Pt. Mugu until one or more hours after this sighting. The Aerial Phenomena Office at Wright-Patterson AFB suggests that it might have been an artificial satellite on which information is not readily available. The object is thus in the unidentified category.


OP 8038
PATH AT
DISAPPEARANCE
0500
0438
SHADOW LINE
O
A
C600
0100
H
d
0300
0200
R
0!00
10°
70°
21°
SOUTH
POLE
.0000 HST


17°
16°
15°
14°
1595 km
1356 km
836 km
A
SHADOW
LINE
638 km
O
H

8. Haleakala II

On 10-11 September 1967 three observers at the Haleakala Observatory who were operating two scanning photometers saw a bright object move from NE to W at a low elevation. The paper tape outputs of each instrument were examined, the airglow photometer was operating with red filters and did not record anything which stood out against the background, but the zodiacal light photometer detected the object four times through a 5080 ± 30 Å filter. Other prominent astronomical features, such as η Canis Majoris, labelled ηCMa were readily identified.

The characteristics and operation of this photometer are somewhat different from the one used in airglow measurements. Its field is 3°; its sweep rate is 2°/sec; and almucantar increments are 1°. Because the focus of attention is the brightness of the zodiacal light a few degrees on each side of the plane of the ecliptic, the sweep was restricted to 160° starting from 0°T, each sweep being completed in 80 sec.

The survey in which the UBO appeared began at 0419 HST and ended at 0451 HST, on 11 September. The tape record is reproduced in Fig. 1 and the data summarized in Table 3.

The object was identified as OP 8038, a sub-orbital missile, which lifted off Vandenberg AFB at 0425 HST. The great circle distance, d, between launch and observation points, is calculated from the rough coordinates:

	Lat.	Long.
Vandenberg	34.5°N.	120.7°W.
Haleakala	21.0°N.	156.0°W.

and it is found that

$$d = 3762 \text{ km}.$$

The position of Haleakala with respect to the shadow-line of the earth is shown in Fig. 5, which is a view of the earth with the southern hemisphere toward the reader. On 11 September the sun rose at 0618.

Table 3

Photometer Data of UBO Sighting

Sighting	HST h	HST m	HST s	Elevation	Azimuth = ψ	τ min	$\Delta\psi$
1st	04	34	25	14^{o}	47^{o}	----	--
2nd	04	35	28	15^{o}	41^{o}	1.05	6^{o}
3rd	04	37	45	16^{o}	36^{o}	2.28	5^{o}
4th	04	38	37	17^{o}	37^{o}	0.87	-1^{o}

At 0439 HST the point of observation, H, was 70^{o} east of its position at midnight. The distance to the point where the body was last seen is HO which, from known quantities is

$$HO = 638 \text{ km},$$

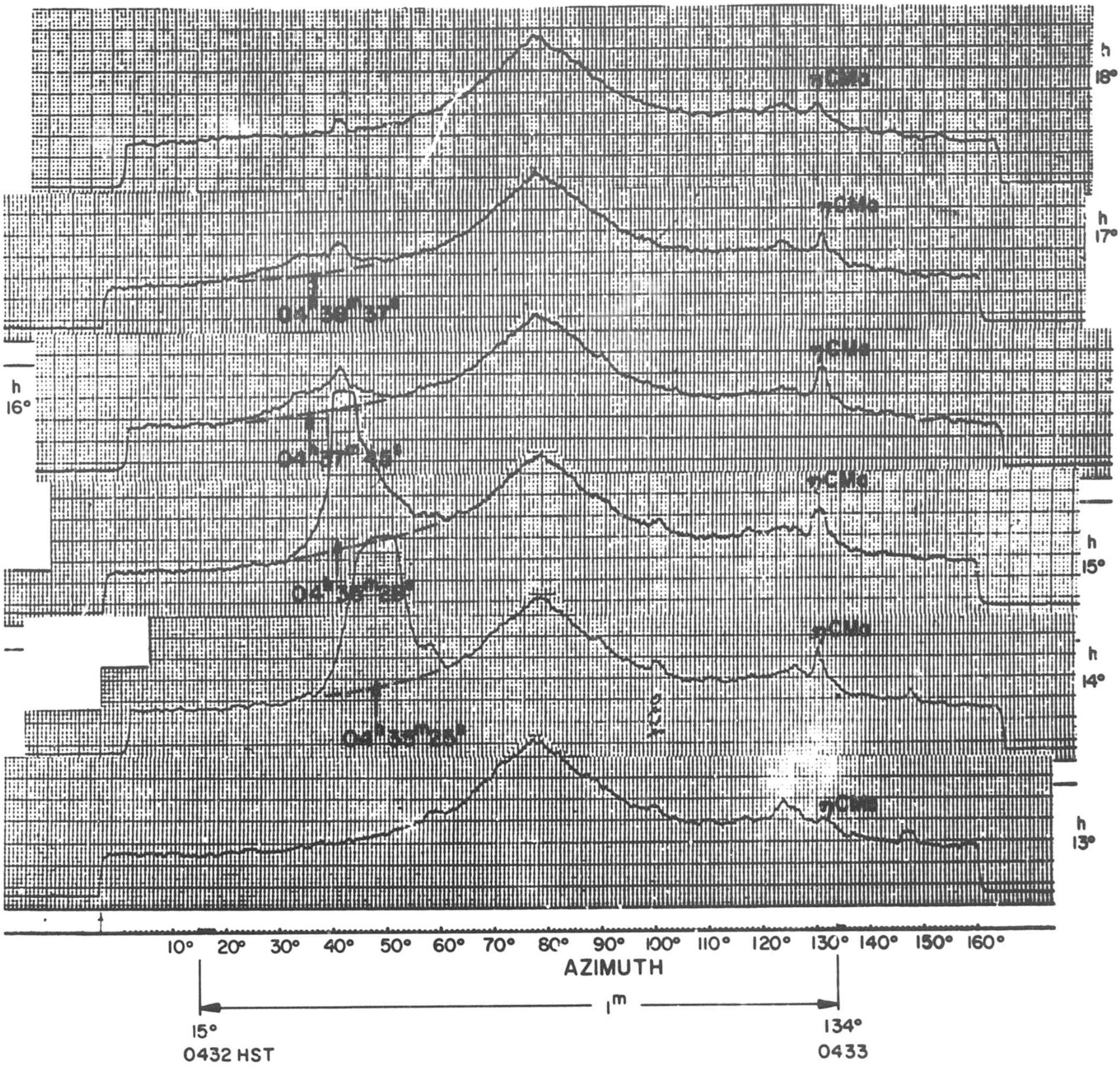
so that by the time the object vanished, it had travelled a great circle distance

$$d' \sim 3100 \text{ km}$$

in 13 m 37 s for an average velocity over the earth's surface of

$$V \sim 228 \text{ km/min}.$$

The distance, d, of the body from the observer at each sighting until iss disappearance, which is assumed to be coincident with the time of last observation, is shown in Fig. 6. From the angular velocity, the angle of approach, β, can be approximately computed; the relevant quantities are listed in Table 4, where ω^{o}, ω_{r} is the angular displacement in degrees and radians, respectively, ϕ is the projected displacement in kilometers and $\overline{V}$ the average velocity between each observing interval, in km/min. The measure of ellipticity is, as before, Sin $\beta = V/228$, where β is the angle between the trajectory and the line of sight.



HALEAKALA II

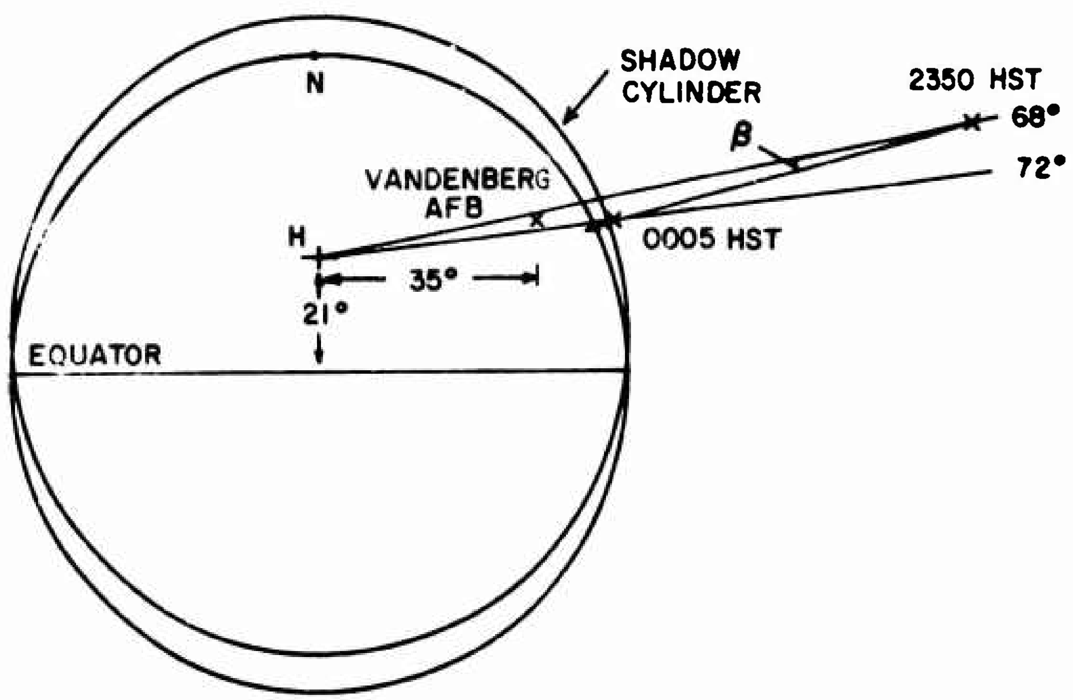
COMPOSITE CHART OF SIX SCANS OF A ZODICAL SCANNING PHOTOMETER, SEPT. 10-11, 1967, SHOWING FOUR BRIGHT PEAKS INDICATED BY THEIR TIMES.

FILTER TRANSMISSIONS: 5080 Å
ALMUCANTAR ELEVATION, h, IN DEGREES
HORIZONTAL SCALE: AZIMUTH INCREASING TO THE RIGHT
VERTICAL SCALE: BRIGHTNESS IN ARBITRARY UNITS

The data were obtained directly from the output tape, eliminating almost completely errors due to manual data reduction. Backlash errors in azimuth are negligible. As a field is only 3^{o}, the uncertainty in altitute is smaller than with a larger field, and remains $\pm 1.5^{o}$, the error in ϕ for the first interval ~5%, for the second ~10% and very high for the third. However, it must be emphasized that the geometrical reconstruction was quite crude and errors introduced by it are probably greater than instrumental errors. Absence of information about the trajectory introduces the most serious uncertainty and the values for d, ϕ, $\bar{V}$ and β should be regarded skeptically. The errors shown in Table 4 for are derived entirely from the uncertainty in the field.

Table 4

Sighting Interval	ω^{o}	ω_r	d	ϕ	$\bar{V}$	Sin β	~β
1-2	$6.2^{+.3}_{-.2}$	$0.108^{+.05}_{-.03}$	1595	172	164	0.72	46^{o}
2-3	$5.1^{+.5}_{-.1}$	$.089^{+.009}_{-.002}$	1356	121	53	0.23	13^{o}
3-4	$1.4^{+1.3}_{-.4}$	$.023^{+.024}_{-.005}$	836	19	22	0.10	6^{o}


SHADOW
CYLINDER
2350 HST
68°
72°
β
N
VANDENBERG
AFB
H
0005 HST
35°
21°
EQUATOR

Even though the reconstruction is very approximate, the magnitude of β indicates a sub-orbital trajectory, because when last seen the body was

$$h \sim 638 \sin 17° + \frac{638^2}{8 \times 6371} \sim 194 \text{ km}.$$

above the surface of the earth, and at this distance it would be expected that $\beta \approx 17°$ for an object in orbit.

9. Radar

The use of radar has spread into many diversified fields since its introduction as an aircraft-tracking instrument at the beginning of World War II. One of the first non-military uses it was put to was tracking weather balloons. Not long after, it was discovered that, given the proper wavelength, radar could detect clouds and the position of rain and hail in storms. Since then its use has extended to tracking satellites, investigating the atmospheres of several planets in the solar system, including our own, determining the trajectory of meteors and predicting their points of impact and studying lightning and violent storms (Battan, 1962).

In general, radar provides information for determining the velocity, range, elevation and azimuth of the reflecting objects in its field of view. Indirectly, it will furnish some data on the state of the matter which is backscattering (reflecting) radio energy; other variables such as temperature and index of refraction can sometimes be inferred.

The resolving power of radar, defined as the minimum distance between two objects (or two parts of one object) necessary to make them appear separate, is poor. Details of the shape of the reflecting object and other features can never be determined except in the most general way and only when the object is very much larger than the radar wavelength. Rayleigh's criterion states, essentially, that, in order for two objects to appear separate, the wavelength of the electromagnetic radiation that illuminates them must be of the same order of

magnitude as, or smaller than, the distance between them. This principle applied to the most common types of radars used in weather surveillance, explains their lack of resolving power because their wavelengths are ten centimenters or greater. In addition, the argument that the resolving power of the all-sky camera is poor because the ratio of image size to emulsion silver grain size is small, applies here: if the range of a typical weather radar is 450 km., the ratio of the area of the image of even large solid objects to the area covered by the scope is exceedingly small.

The range resolving power of radar is also dependent upon pulse duration. The limit of resolution in the direction of propagation is half the linear dimension of the pulse because at intervals less than that the echo formed by the leading edge of the pulse reaching the more distant object overlaps the echo formed by the trailing edge of the pulse returning from the nearer object. Thus, if the radar is "looking" at two objects in its "line of sight," and if its pulse duration is 1 μsec., it will not display as separate from each other, in-line targets whose ranges differ by less than 500 ft.

Radar reports information in three coordinates: range, elevation, and azimuth. The resolving power in the range coordinate is determined by pulse duration. Resolving power in elevation and azimuth depend upon the same conditions that apply to optical resolution. Rayleigh's criterion for the optical resolution of a telescope can be used for this purpose, if the radar antenna is circular and its diameter is regarded as its aperture. Resolving power is proportional to the ratio of the wavelength to aperture (diameter). This is another way of saying that the ratio determines the angular beam width of a radar transmitting-receiving antenna. Resolving power is determined for this case by the equation

$$r = 70°(\frac{\lambda}{D})$$

where λ is wavelength, D is antenna diameter, and 70°(= 1.22 rad.) is the angular size of diffraction disc image of a point source for unit $\frac{\lambda}{D}$ ratio as derived by Rayleigh. (For other than

antennas with a circular aperture, resolving power must be separately computed for the vertical and horizontal planes). Applying the equation to a radar with a wavelength of 3 cm., and whose parabolic antenna has a diameter of 3 m., the beam width, and therefore the resolving power, is found to be 0.7^{o} of arc in elev tion and azimuth.

Radar is frequently able to see targets virtually undetectable by the unaided eye or on photographic film. This greater sensitivity is due to marked differences in the signal-to-noise ratio of wavelengths employed by radar compared to the optical wavelengths upon which the eye and the camera must rely. The atmosphere is almost completely transparent to radar wavelengths between 3 cm. and 10 cm. It scatters such waves hardly at all. At optical wavelengths, it is still relatively transparent, but air scatters energy appreciably, especially at the short (blue) wavelengths (Rayleigh scattering): hence, the blue sky. In addition, unlike the radar case, there is a powerful source of optical noise present in the daytime sky -- the sun. Thus, a pale blue object seen against the sky is nearly invisible to the retina or to photographic film, yet, if constructed of metal, the object will reflect radar waves strongly.

Design of a radar to track targets very much smaller than the wavelength takes into account that for a given wavelength, backscattering power varies as the sixth power of the target size (Rayleigh's Law of Scattering) and, conversely, for a given target size the power varies inversely as the fourth power of the wavelength. Furthermore, atmospheric attenuation of the beam increases as frequency increases. The balancing of these factors results in the choice of a 10-20 cm. wavelength for radar which are to survey extensive storms such as hurricanes; 3-10 cm. for tracking metallic objects; and 1-3 cm. for studies of rain and hail distributions (Battan, 1959).

The first exact theory of scattering of electromagnetic waves by a sphere was developed by Gustav Mie in 1908. In this theory, the dielectric constant and therefore the index of refraction of the sphere determines in large part the amount of backscatter at any wavelength (Born, 1964). For example, the backscatter from a hailstone is enormously greater than that from a raindrop of equal size, and, as a result, radar can provide data for estimating the amount of ice or hail in a storm cloud. In effect, therefore, it can give information on the state of matter in the scattering object, for example; it can distinguish between wet and dry hailstones.

Anomalous reflections called "angels" can sometimes be ascribed to certain atmospheric conditions. Temperature inversions cause rapid changes in the index of atmospheric refraction at the interfaces of the layers and such changes can give rise to radar echoes exactly as similar conditions account for mirages in the case of visible wavelengths. (See Section III, Chapter 5 Section VI, Chapter 5.

As would be expected from Maxwell's equations, radar echoes will be produced by regions of high ionization where there is an appreciable density of free charges. This is the reason why lightning paths are visible to radar. The density of charges in the trail of a meteor is different from that in the immediately surrounding space, and the radar echo arises from this difference in space charge, not by reflection from the nucleus of the meteor itself (Lovell, 1954). Depending upon the magnitude of the radar "cross-section" some "angels" can be ascribed to echoes from birds or even insects. "Cross-section" is better defined as the ratio of the reflected power per unit solid angle to the incident power density; in other words, it is a measure of the effectiveness of the target in reflecting radiation and will have a different value for each wavelength. Inasmuch as birds and insects are usually smaller than radar wavelengths, their actual dimensions cannot be measured, although their radar cross-section can be (Glover, 1966). This quantity, for several species of birds and insects is tabulated below as a function of radar wavelength:

Table 5

Target	Wavelength	Mean cross-section cm^2
Hawkmoth	10.7	1.0
Honeybee	10.7	3.0×10^{-3}
Sparrow	10.2	15.0
	71.5	2.5×10^{-2}(a)
	3.5	1.9
Pigeon	10.2	80.0
	71.5 (a)	11.0
Pigeon	3.5	15.0
	3.5	1.1 head
		100.0 broadside
		1.0 tail

(a) Transmitted beam vertically polarized; received echo also vertically polarized.

(Table taken from Glover (1966) and Conrad (1968).

The extreme sensitivity of radar is well illustrated here: The insect targets were at least 10 km. distant and the birds at ranges between 10 and 20 km. when the measurements were made. Because of the poor resolution of the radars, the cross-section is simply a measurement of relative backscattered power and now the actual spatial extent of the object on the radar scope. In other words, the moth can be distinguished from the sparrow only by determinations of the power received rather than by shape and size; the head of a pigeon cannot be differentiated from the tail.

> The radar return does, however, contain information which provides a basis for identifying an unknown point target as a bird....

> Thus, the radar return from single birds in flight differs...from other possible point or dot targets, such as aircraft, swarms of insects, several birds together, or small clouds or other meteorological structures (Conrad, 1968).

Weather Radar:

Of the 14 types of radars used by the U.S. Weather Bureau only the WSR-57 which is equipped with a 35 mm. camera appears to be adaptable to UFO searches. The salient features of this instrument are enumerated below:

WSR-57

Wave Length cm.	Pulse Length Rep. rate	Peak Power Output K.W.	Beam Width	Sweep Character-istics	Scopes	Range	Alti-tude
10.3 (5 and 2.5 cm. planed but not yet on order)	0.5 micro/sec at 658 pulses per sec. or 4.0 micro/sec at 164 pulses per sec.	500	2°	Automatic, manual in altitude or azimuth at 0-24°/sec	PPI RHI R A	464km.	-10° to +40°

(Source: U.S. Dept of Commerce)

These radars are placed around the perimeter of the Weather Network and are interspersed with the eastern stations of the Praric Network in Minnesota, Iowa, Kansas, Oklahoma, Missouri and Illinois. They are, therefore, well located to furnish corroboration of sightings in any future investigations.

The sky coverage of these radars is obviously less than that of the airglow photometers since they are limited in their choice of elevation and they have only a 2° sweep width.

The photographic program which has been carried over the last few years consists in taking one scope picture of one sweep every 15 min. in times of clear weather and more frequently when storms were developing. These films are available for inspection, but the Colorado project

made no attempt to search for confirmatory evidence of reported sightings because each photograph covers only 1.7% of each hour of elapsed time.

Meteor Radar

The facilities of the Radar Meteor Project of the Smithsonian Institution are located at Long Branch, some seven miles south of Havana, Ill. They consist of a network of eight receivers and one 4 Mw, 40 MHz transmitter, with antennas bearing 113°T. This direction was chosen as the most favorable one for the detection of faint meteor trails.

The main lobe of the radiation pattern from the two transmitting antennas is inclined upward at 45° and has a half-power horizontal width of ~ 20° and a half-power vertical width of ~ 11°.

Pulses of 6 μsec. duration are emitted at the rate of about 1300 per second, so that the echo from an object 200 km. distant will return within one pulse cycle. An object in the beam at 200 km. will be about 140 km. above Decatur, Ill. The Havana radar is thus designed to scan approximately the same volume of sky monitored by an image orthicon located at Sidell, (near Urbana) Ill. (see Section 12).

The radar will detect meteors as faint as $m_{rad} = +13$ for counting purposes, and $m_{rad} = +1'$ and will acquire echoes from 3,000-4,000 meteors/hr.

The system is capable of receiving echoes from objects at almost any distance from the transmitter. In order to limit the information to "suitable" meteors, meteor-recognition logic has recently been installed which filters out extraneous signals such as those from aircraft. These echoes are, however, visible on the monitoring oscilloscopes and are characterized by a persistence greater than that of meteors. Data pertaining to "suitable" echoes is recorded on magnetic tape. Similar, but unfiltered data is simultaneously recorded on film (Smithsonian, 1966).

During 1967, many non-meteoritic echoes were seen on the oscilloscopes and recorded in the Havana log book. Using the film record, the Colorado project sought to determine how many of the UFOs sighted during 1967 in a radius of ~ 140 km. from Havana, had resulted in an

echo which had been both filmed and logged. Of nine cases (the same used to test the orthicon), seven had occurred when the station was not operating. The eighth case covered a series of sightings over a period of 10 days during which the station was operating. Unfortunately, only very sketchy observing data were available. The object was seen from Kilbourne, about five miles south of the transmitter, "over the west south-west horizon." Station attendants had been alerted that unusual objects had been seen in the area. The absence of entries in the log book implies that nothing unusual appeared on the scopes. This is not surprising because echoes of objects very close to the station are lost in the display formed by the transmitted pulse, particularly at low altitudes. If the objects had been farther away but bearing ~140°T (WSW) they would not have been located within the main lobe of radiation bearing ~113°T. Objects outside this zone of maximum transmitted power would return echoes too faint to be observed against background "noise."

The ninth object is the one that the image orthicon recorded in a test run on November 7th, 1967 at 2330 ± 3 m. It was subsequently identified as a fireball. No simultaneous radar sighting was made because the radar was not in operation.

10. The Image Orthicon

One of the important problems in meteor physics is the cross-correlation by simultaneous radar and optical meteor observations of ionization and luminous efficiencies as functions of velocity.

The development of the image orthicon has made such cross-correlation studies feasible. The instrument is a conventional vidicon television camera modified so as to increase its sensitivity. This is achieved by adding an image intensifier ahead of the scanning mechanism in the camera. The result yields a sensitivity equivalent to an ASA rating of 100,000. Such extreme sensitivity permits detection of meteors having a limiting magnitude of about +7. This is well within the equivalent M_{rad} range detectable by radar, and considerably superior to the capability of any photographic system except the 48 in.

Schmidt telescope at Mt. Palomar. Tests show that the image orthicon will detect 20-30 meteoroids per hour.

The image orthicon site in Sidell, Ill., about 35 mi. SE of Urbana, was chosen by the Smithsonian Institution with two objectives in mind. Using a lens having a 16° field (the optimum lens for meteor surveys), the image orthicon is sited to survey approximately the same area of sky over Decatur as that covered by the 20° beam of the Long Branch radar (see previous section). But whereas the radar is sited so as to track the meteor trails at about right angles, the image orthicon is located so that its optical axis is more nearly parallel to the meteors' paths.

Linked by microwave and radio, the radar and the image orthicon are able to determine times within 10^{-2}sec., thereby minimizing ambiguities as to the identity of the objects observed.

As in conventional television, an 875-line scan samples the tube target in two sets of sweeps of alternate lines, each requiring 1/60 sec. When the alternate sweeps are interlaced, flicker and resolution are greatly improved. The electronic image is recorded on magnetic tape and can be immediately played back for viewing on a monitor. Used in this way, the high sensitivity of the image orthicon permits the acquisition of moving aerial objects that would be undetectable photographically because of the effect of trailing. Photographic records of the monitor images can be recorded by a 35 mm. camera operating at any desired frame speed.

The sensitivity of some image orthicons can be further increased by operating them in the integrating mode. In this procedure, the electronic image is swept away less frequently, thereby allowing the photoelectron population due to ultrafaint images to build up. The Smithsonian image orthicon has no provision for this technique, nor does its camera permit the making of time-lapse photographs which are preferable when the device is operating in the integrating mode (Williams, 1968).

During 1967 there were nine sightings of UFOs within a distance of ~ 200 km. from Urbana. (These were the same sightings which were

correlated with the radar records.) Eight of the sightings occurred before testing of the image orthicon began in August. The ninth was a sighting on 7 November at 2230 $\pm$ 3 min., of a bright object between Urbana, Ill. and Lafayette, Ind. This event was recorded on the image orthicon tape during a test. A film of the tape clearly shows a bright mass moving rapidly across a corner of the field. The object is badly resolved due to its great brightness, but the shape of the image suggests that the meteoroid had already broken into two pieces. Preceding the meteoroid image is a large ghost image which is the result of reflections between the lens elements. Just prior to the appearance of the meteor, a small object can be seen moving at 90° to the fireball trajectory. This object has been identified by Wright-Patterson AFB as a satellite.

11. Proton Magnetometers

The variation in the magnitude and direction of both the horizontal and vertical components of the earth's magnetic field is of such importance in geophysics that a network of some 240 geomagnetic observatories have been deployed by several countries at stations all over the globe (NAS 1968). Thirteen of these stations exist in the continental United States and of these, three are situated on the western edge of the Prairie and Weather Radar networks.

Most of the instruments at the geomagnetic stations are proton magnetometers. These instruments have a sensitivity of about 1 γ (= 10^{-5} gauss) in magnetic field strength. This means that the instrument is capable of detecting at a distance of 185 m. the field strength along the axis of a single-turn circular conductor 20 m. in diameter in which a 100 amp. direct current is flowing. In addition to this extreme sensitivity to field-strength fluctuations, the proton magnetometer is capable of detecting 0.1' of arc in declination, defined as the deviation of the horizontal component of the earth's magnetic field from 0°T. Since the mean strength of the earth's magnetic

field at midlatitudes is about 50,000 γ, the instruments are sensitive to about one part in 50,000 of the earth's field.

Assuming a model consisting of a line current in the vortex extending from the ground to a height of 10 km. and an image current of equal length in the earth, Brook (1967) calculates that the current in a tornado, which caused a 15γ deflection in a magnetometer 9.6 km. distant, was about 1,000 amp. Revising the model to make it more realistic, he assumes that a 20 km. horizontal line current 6 km. above the earth joins a 6 km. vertical line current to the earth together with an equal earth image. The current necessary to produce the observed 15γ field is then only 225 amp.

Consideration of the electromagnetic effects produced by tornadoes suggests that some UFO sightings may have been stimulated by these storms, and that continued photographic, geomagnetic and radar observations would be useful in studying them.

The claim that UFOs produce powerful magnetic fields could also be investigated by proton magnetometer measurements. The problem, however, is a familiar one: thus far it has not been possible to bring instrumentation to the scene of a sighting while UFO phenomena were still observable.

Papers by Vonnegut and Weyer (1966) and Colgate (1967) contain extensive lists of references on tornado energy phenomena. Much of the information for this section was supplied by Dr. Joseph H. Rush, High Altitude Observatory, National Center for Atmospheric Research, Boulder, Colo.

12. Lasers

The use of lasers in tracking objects is analogous to the use of radar, the principal difference lying simply in the wavelength of the radiation in the emitted pulse. As in radar tracking, the information obtained is range, azimuth, and altitude, but the accuracy of laser

ranging is expected to be better than in 3 cm. radar by a factor of two, because of the smaller effect of atmospheric water vapor on the refractive index at the laser wavelength.

The extremely good collimation of a laser beam, where the angular spread is less than 2×10^{-5} radians (a few seconds of arc), is a two-edged sword insofar as the development of laser ranging is concerned. The narrow beam increases the accuracy of azimuthal data and diminishes the transmitted power required to yield a detectable return signal; but this very narrowness increases the difficulty of scoring a hit on a rapidly moving object in low orbit.

Laser ranging has been in the developmental stage for only a few years and, at the present state of the art would be of only limited value in UFO investigations. However, laser technology is advancing rapidly and it seems quite probable that future laser ranging devices could be useful in UFO searches.

13. Observations and Comments

The description of a phenomenon requires the collection of many of its qualitative and quantitative aspects. If the data relating to these aspects is sufficient to permit the construction of a model then this model can be identified as belonging to one or another known category of phenomena if their mutual similarities are numerous enough. Conversely, if the similarities are not numerous enough, it may be necessary to identify the model as a member of a completely new category.

In the majority of UFO sightings, the amount, type and quality of the data have been insufficient even to describe the event, to say nothing of identifying it with a known classification. Data from many other sightings have been adequate for identification with familiar phenomena. to a reasonable level of confidence, but in no case have the data been either detailed or accurate enough to class the event as a new phenomon.

The lack of instrumented observations has curtailed investigation of a number of events which sounded fascinating and on the threshold

of revealing something novel. No matter how detailed or how intelligent the reports of observers, qualitative statements could not serve to define an unfamiliar phenomenon. To do so requires a quantitative description of a number of basic characteristics, some of which are listed below:

1. Dimensions.
2. Position, that is, coordinates in some frame of reference, usually with respect to the observer.
3. Shape.
4. Mass.
5. Motion - velocity and accelerations, particularly with reference to the method of propulsion.
6. Interactions with other systems - effects of electric and magnetic fields on surrounding objects, emission of energy in the form of exhausts, light and sound, aerodynamic lift, ionization.
7. Matter primarily involved - the composition and state of matter and its temperature, rigidity and structure.
8. Origin - the genesis of the phenomenon, the conditions which gave rise to it, its presence in and mode of transport to the region in which it was observed.

Instrumentation to acquire knowledge of these characteristics must be designed with appropriate regard for the behavior shown both by UFOs and some other phenomena which can be loosely classed together as objects difficult to identify. Any instrumentation for the detection and identification of these objects must be elastic enough to cover the wide range of expected behavior. A comparison of various salient characteristics of some objects observed in the atmosphere is set out in Table 6.

An explanation of some of the statements in the table is of interest:

Duration:

1) The large majority of meteors have been observed to have a duration shorter than 15 sec. Thus if a meteor moving at 30 km/sec at an altitude of 80 km. is visible over 160° of sky, its path

Table 6

Characteristics of Some Objects Observed in the Atmosphere

	Meteors	Satellites and Satellite re-entries	Aircraft	Tornadoes	UFOs
Point source (P.S.) or extended object (E.O.)	P.S. unless fireball	P.S. unless re-entry	P.S. by night E.O. by day	E.O.	P.S. by night E.O. by day
Self-luminous	yes	reflected light yes (re-entries)	yes, navigation lights	yes?*	yes, at night
Luminance	high	low	low	low	low to high
Direction of motion-unpredictable, linear, ballistic or orbital	linear or ballistic	linear or orbital	straight or slowly curving	slowly varying	unpredictable
Electromagnetic effects, other than visual	some evidence exists**	none	none	possible but not established**	sometimes
Close approach to or contact with ground	infrequently	re-entry only	yes	yes	so reported
Distance to observer	many miles	many miles	from close to far	usually several miles	from close to many miles

*(Vonnegut and Weyer 1966)
**(Romig, 1963)
***(Vonnegut, 1968)

Table 6 (cont'd)

Characteristics of Some Objects Observed in the Atmosphere

	Meteors	Satellites and Satellite re-entries	Aircraft	Tornadoes	UFOs
Duration of appearance	1-15 sec.	<5 min.	<5 min.	a few sec. to many min.	a few sec. to many min.
Velocity range	<17 km/sec	<8 km/sec	<0.6 km/sec	<0.03 km/sec	unpredictable
Altitude	10-100 km.	100-2,200 km.	<26 km.	>13 km. and <19 km.	zero to very high
Direction	isotropic	Constant; W to E, polar or E to W	isotropic	isotropic	isotropic
Other			characteristic illumination	most common in central states	no apparent geographical distribution

length will be

$$d = 2x\frac{80\ \text{km.}}{\tan 10^\circ} = 900\ \text{km.}$$

so that it will have a maximum distance from the observer of 450 km. Therefore, it will be visible for not more than

$$t = \frac{900}{30} = 30\ \text{sec.}$$

However, most meteors do not usually have the luminance to be seen at a distance of 450 km.

2) In the case of satellites, one which has a 90 min. period at an altitude of 200 km., and can be seen over 160° of sky, will be visible for about 4.5 min.

3) Tornadoes occasionally persist for a long time and travel many miles.

Velocity range:

1) The lowest meteor velocity (prior to the last few seconds before impact) is ~ 17 km/sec. The greatest velocity imparted artificially to a small object is ~ 14 km/sec by means of a four-stage rocket in a ballistic trajectory and a final boost with a shaped charge. (McCrosky, 1968)

2) Satellites with a near-escape velocity of 17,000 mph have a velocity of only 7.6 km/sec.

3) For aircraft, 2,000 km/hr or ~0.6 km/sec.

4) A tornado usually moves at 5-70 mph., (0.002-0.03 km/sec).

Altitude:

1) The Prairie Network attempts to get stereo-pairs of meteor photographs for trajectories at 40-80 km. in altitude and downstream single photos at 10-40 km. altitude to predict the point of impact.

2) Perigee and apogee of most satellites lie in the range of 100-2,000 km.

3) Aircraft: 26 km. ≈ 16 mi. ≈ 80,000 ft.

4) Vonnegut (1968) states that although thunderstorms spawn tornadoes, the higher the storm the greater the probability of formation. "Ordinary" thunderstorms at an altitude of about 8 mi. rarely produce tornadoes while those at 12 mi. often do.

Azimuth:

1) Meteors appear in a region bounded by a few degrees on each side of the plane of the ecliptic and their trajectories will be oriented isotropically with respect to their points of origin.

2) Satellites lauched from Cape Kennedy will travel from west to east, with a small southward component; those launched from Vandenberg AFB are most often in a polar orbit, though some are in retrograde orbit.

3) Aircraft, of course, will be seen moving in any direction.

4) Tornadoes seem to have no observable directional pattern.

Review and Discussion of Several Instrumental Methods

1) The Prairie Network covers about 80% of the volume of space above each camera station. This is as good a coverage as can be found with any instrument except certain types of radar, all-sky cameras, and airglow photometers.

2) The coverage is continuous, during periods of good visibility from dusk to dawn, or, roughly, about 30% out of every day. Radar has the advantage of daytime coverage over optical systems, but resolution and identification is not as good. The presence of "angels" and other anomalies, complicates the interpretations.

3) Certain other means of detection, such as photometric scans, have much longer ranges and therefore probe very much larger volumes of sky. But these systems suffer from the same disadvantages as radar.

4) No other optical network exists which is as extensive as the Prairie Network, the coverage of which is ~0.13 of the sky over the U. S.

5) The network has been designed to produce data which allows the direct computation of altitude, azimuth, velocity, and brightness from which loss of momentum and impact coordinates can be found. Radar will acquire the same data but will record neither the visual identifying signals emitted by a plane nor the brightness of a meteor.

6) Objects recorded by a photographic time exposure show a continuous projection of their position in time. In many radars the object is located only once every sweep and since each sweep may have a period of six to 15 sec., rapid course changes may result in an inability to identify successive images as belonging to the same object.

7) Although the network is at present purely pictorial, it may shortly be improved by the addition of a spectrometric camera at each station.

8) Devices such as airglow photometers cover the sky well but also have shortcomings similar to radar because each scan at a given zenith angle requires a relatively long time and a complete sky survey requires several scans taking several minutes.

9) Most photometric scanners plot intensities as a function of time on paper tape. Reduction of this data to coordinates is not as accurate as interpretation of the network film, although it is good enough for airglow and aurora studies.

10) Differentiation between near-orbital or ballistic objects and the star background is much simpler in network photographs than on photometric scan tapes because star trajectories on film are obvious, whereas on tapes a pulse produced by a reflecting or self-luminous object can be distinguished from a pulse produced by a star only by comparing its coordinates with those given for stars.

11) Scanning radar sky coverage is very good, but identification of objects photographed on the radar scopes is much more difficult that objects seen photographically, both because of poor resolution and because of the lack of characteristic patterns such as flashing lights on planes, and so forth. Weather radar, however, would be a useful adjunct to a photographic patrol, particularly

since a portion of the weather radar system is interlaced with the network. In general, it can be said that the most effective use of radar lies in confirmation of velocity, range and direction.

12) Image Orthicons and Vidicons: The use of these photoelectric devices is growing, largely because their sensitivity is greater than film by a factor up to 10^4. Such systems can also store and reproduce the image immediately. These attributes make them valuable instruments in investigations of aerial phenomena of any kind, including UFOs.

13) A number of UFO reports have indicated electromagnetic interactions with terrestrial systems: radio and TV interference, stalled internal combustion engines, and the like. It would be desirable to investigate the frequency with which UFOs exhibit such interactions as well as the field strengths and direction. No network of stations making routine recordings of atmospheric electric potential exists at present in the U.S. Electric potential measuring devices might be incorporated into joint geomagnetic weather radar and Prairie Network system at a later time.

14) There have been persistent reports that sometimes sounds accompany the passage of large meteors (fireballs) and the re-entry of satellite debris. There is evidence that these sounds have been heard at great distances, sometimes simultaneously with the time of passage. This suggests that fireballs give rise to electromagnetic fields which either interact with the surroundings of the observer, or directly with the observer himself, to produce audible waves (Romig, 1963, 1964). Stations containing geomagnetic or electric potential measuring devices should also be equipped with tape recorders and appropriate acoustical sensing devices.

15) Other instruments such as ultra-violet and infra-red sensors, and radiation-counters would also be desirable.

Existing Instrument Systems of Limited Value

1) The Super-Schmidt cameras developed for meteor studies are sensitive and have a 55° field but they are few in number

and individually cover only a hundredth of the area of sky covered by one Prairie Network station. The Baker-Nunn cameras which were designed for satellite tracking have a much smaller field, and although there are perhaps 16 of them in all, they are scattered all over the world.

2) Sky surveys made through large astronomical telescopes cover too little sky at each exposure. Because of their slow photographic speed, only very bright objects moving with respect to the star background will be recorded.

3) The Tombaugh Survey for small natural earth satellites was an extremely systematic search (Tombaugh, 1959). This technique would hardly be suitable for photographing UFOs.

The capabilities of existing instrumental systems to record the characteristics necessary for quantitative descriptions of UFOs vary widely. The Prairie Network can supply data on position and motion at all times; under ideal conditions it might be capable of determining dimensions and [illegible] but it cannot directly describe mass, interactions, the matter associated with the event, its origin or manner of locomotion.

Radar is more limited in its information return. It can report position and motion, even when the phenomenon is invisible to the network, but it cannot furnish information on any other characteristic, with the possible exception of the state of matter. Photometric scanners are even more limited.

Determining mass and kind of matter, and extensive analysis of the structure and organization of an UFO require that such an object, if one exists, be made continuously available for instrumented study.

If all the eight characteristics listed at the beginning of this section describe adequately an UFO, then no network, simple or complex as presently constituted, can help us far along the road toward the identification of that type of event which today defies explanation.

What is required is a modified and extended network, so designed that its component systems complement each other, and so integrated

that it can provide storable data in a form suitable for interdisciplinary study.

More specifically, the network should be organized along the following lines:

1. In the interests of economy and speed, arrangements should be made to have access to the output of the Prairie Network, and the cooperation of its investigators.

2. Similar arrangements should be made with the Weather Radar Network and a program of photography developed along lines suitable for the acquisition of data on tornadoes and other transient phenomomena not detectable by time-exposure photographs.

3. Simultaneous observations with the several geomagnetic observatories which lie in or near the combined Prairie Network-Weather Radar nets should be provided for.

4. Link these three networks, and other devices, such as tape recorders and radiation monitors, together to a single time base. This step is important, for example, in testing reports that fireballs have been heard at the same time as t[illegible] appearance, although their distance from the observer would normally require a many-second interval between sight and sound.

5. The tedium of a patrol can be relieved by the installation of various automatic sensors, but the degree of discrimination offered by these devices is often not as great as that of the human eye. It is true that the eye is, in general, incapable of making quantitative and reliable observations suitable for network studies, but it is a very sensitive detector with a wide angle of view and search, and these qualities should be used. It will be recalled that Tombaugh supplemented instrumental with visual search for small natural satellites. Visual search could probably benefit from a tie to an "early warning" communications network of amateur radio operators.

6. Photoelectric and electromagnetic sensors can not only give early warning of the approach of an event of interest, but also are capable of actuating detecting and recording instruments

much more rapidly than the human on patrol.

7. The operation of the network can be made flexible. Costs can be reduced by maintaining a minimum staff in maximum collaboration with other search organizations.

8. Combined network operations should start as soon as the photographic, radar and geomagnetic nets are linked in time. Installation of additional instrumentation should be deferred until a backlog of observations has been studied.

The cost of a program organized in this way should be two to three orders of magnitude less than most current proposals. The capital and operating expenses of the Smithsonian Meteorite Recovery Project can be taken as a measure of these costs. It is estimated that to duplicate the Prairie Network would cost about $150,000, not including the cost of the cameras and lenses which were lent by the U.S. Air Force.

It is difficult to arrive at that part of the total operating expense for meteorite research applicable to an UFO network because the cost figures include operation and data reduction of Super-Schmidt cameras at Wallops Island, and the new image orthicon installation at Urbana in conjunction with the radar at Havana, Ill. The total annual expense, however, can serve as a guide for the proposed combined network:

Running and maintenance, Lincoln, Neb.	$25,000
Supplies: film, chemicals for 64 cameras ($500/camera/year)	32,000
Scanning of film	10,000
Data reduction, all projects	65,000
Astronomers' salaries etc.	28,000
	$160,000

Assuming that the combined network will not have to bear any of these costs, it would seem that, initially, at least, its expenses could be limited to the salaries of a principal investigator, a junior investigator and one technician, the cost of film exposed by the Weather Radar scope cameras, travelling expenses and miscellaneous items. It

would be surprising if expenses would exceed $50,000 annually.

Because of the rarity of the UFO phenomena, the investigation should continue for a minimum of five years. It is anticipated that the total cost would exceed $250,000, however, because preliminary results would suggest equipment modifications and additions.

14. Recommendations

The problems involved in sightings of UFOs warrant the mounting of an instrumented effort to arrive at reasonable identifications of the several phenomena involved, and to add to the limited knowledge which exists about those phenomena. Present knowledge amounts to little more than suppositions.

Popular preoccupation with the notion that UFOs may be intelligently guided extraterrestrial space ships has had one undesirable effect: it has imbedded in the term "UFO" the unfortunate connotation that if a phenomenon is unidentified it must somehow be extra-terrestrial.

It has become apparent that the clarification of the "unidentifiable 1%" referred to by Hynek (1966) may more likely result from investigating several rare phenomena, rather than one. If evidence of extraterrestrial intelligence is uncovered by the study, then the goal of the research can be changed and a full-scale investigation launched.

Until that time comes - if it does - the pursuit of knowledge about the less dramatic phenomena can go on in a modest way, using already established facilities, extended when, as and if the need arises, with additional equipment.

With the de-emphasizing of the ETI hypothesis must also come a complete elimination of the term "UFO." Its connection with an otherwise soundly-based research program can serve only to impair that program's effectiveness. After all, it is beginning to look like a misnomer in certain cases: the sighting may not involve an "object," meaning a solid mass; it may not "fly" in the sense of having aerodynamic lift, and often it remains "unidentified" only briefly.

Several suggestions have been made on investigating what will now be called "strange phenomena." Dr. James E. McDonald, of the University of Arizona has recommended a program of several steps, the cost of which would range from "a few tens of millions of dollars" to "global expenditures at the level of billions of U.S. dollars per year." (McDonald, 1967, 1968).

W. T. Powers of the Dearborn Observatory has discussed the design of a new photographic network covering 1% of the area of the United States; the cost for this coverage would amount to about $\$2x10^6$ and $\$2x10^7$ for a 10% coverage of the U. S. (Powers, 1968). Dr. G. H. Rothberg in his report to this project of an attempt at first-hand observations and UFO photography recommends new camera design and a "small" effort costing perhaps $\$1x10^7$ (see Case 27). Larry W. Bryant, after suggesting an Earth-surveillance satellite especially designed for the purpose of monitoring UFO activities, finds that it might cost $\$5x10^7$ and require five years' effort from funding and design until launch (Bryant, 1967).

The UFO phenomenon is extremely rare. Whereas some 500 meteors per year have trajectories which can be reconstructed from photographs, and none has been recovered in the three or four years of the Prairie Network's existence, Hynek states that only 600 UFO sightings since 1947 have remained unidentified by the Air Force (Hynek, 1966). If this number is adopted as the equivalent of the "1% unidentifiable" events, sightings due to strange phenomena occur at the rate of only 30 per year. Other arguments further lower this figure to 18 or less per year (Page, 1968).

The number of sightings of rare phenomena is so low that it is impossible to make a meaningful geographical distribution. Whether the site of the Prairie - Weather Radar - Geomagnetic Network will eventually turn out to be the best location cannot now be predicted; its present advantage lies in the fact that the three detecting systems are interlaced over a small area, thus facilitating an investigation involving several disciplines.

It is because these sightings are so infrequent that the recommendation is made to use existing facilities, wherever they happen to be, and to proceed with such studies in a measured and thoughtful manner.

Chapter 10
Statistical Analysis
Paul Julian

> For the most part, statistics is a method of investigation that is used when other methods are of no avail; it is often a last resort and forlorn hope. M. J. Moroney, *Facts from Figures*.

Statistical analysis may be described as the quantitative treatment of uncertainty. In the broad sense, it is certainly more than that. To many people the term 'statistics' is synonymous with 'data' and a large portion of those who do statistical analysis concern themselves with collecting and summarizing data. But when data so treated are used to formulate and test hypotheses, probability is immediately involved and the quantitative treatment of uncertainty begins.

The malaise engendered when one deals with uncertainty and an insufficient knowledge of statistics probably account for the viewpoint expressed by Moroney. Many people, scientists among them, are uncomfortable dealing with uncertainty (even though, without being aware of the fact, they are constantly doing so) and their opinion of statistics is consequently somewhat colored.

We are interested here in whether or not statistical analysis of UFO sighting reports is likely to be informative as to what the phenomena are but not as to how they are reported. We make a distinction, initially, between studying the phenomena of UFOs and studying how people report UFOs. It is likely that the two cannot be completely untangled and, further, that the former is impossible without some idea of the latter. However, attempts have been made and probably will in the future be made to use aggregated sighting report data to study the UFO phenomena because that data source is certainly the largest and most comprehensive of any we have available with which to attack

the problem. Throughout this chapter we will be concerned, then, with the role of statistical methodology in studying the UFO phenomena.

Since statistics deal with uncertainty it might seem an attractive candidate for a central methodology in UFO research. The purpose of this chapter is to discuss the place of statistical analysis in the study of the UFO problem. We will be specifically interested in the testing of hypotheses and with decision procedures and not simply in the aggregation of data.

The nature of the UFO problem coupled with the nature of statistical methodology, first of all, results in questions posed in the hypotheses which may not be particularly satisfying. For example, we might want to ask "Is there a 95% (or 90% or 99%) chance that UFO sighting reports include observations of objects not of terrestrial origin?" But by the nature of the data we are forced to ask questions such as "Is there a 95% (etc.) chance that the characteristics of reports classified as 'knowns' differ from those for which no explanation has been suggested?"

One reason for the inability to ask questions or state hypotheses which are directed specifically at solving the problem of UFO phenomena is that they occur in nature and out of our direct control. Except perhaps for some psychological studies, we cannot place 'the UFO problem' in a laboratory and measure and study it -- we must accept it as it happens. In statistical terms, we cannot design statistical experiments to test particular question.

The second, and more profound, difficulty is presented by the rather obvious fact that it is impossible to formulate meaningful statements, questions, or hypotheses about the manifestations of unknown phenomena. We can, of course, examine the data and see what manifestations there are in the sample data, but we are severely limited in the nature of the conclusions we can draw, again, because of the unknown nature of the phenomena. The difference here is subtle, perhaps, but important.

An instructive, but certainly not unique, way of looking at this difference is to invoke the traditional dichotomy between inductive and

deductive reasoning in science. The deductive approach would operate by, say, assuming that UFOs are a manifestation of Extra Terrestrial Intelligence; or, perhaps, simply represent a class of unknown atmospheric optical or electromagnetic phenomena. Given one or the other assumption it would next follow that some hypotheses about the characteristics of UFO reports be constructed. But because in both assumptions we are dealing with something unknown, how would we go about setting up such hypotheses? Such an approach from a statistical point of view at any rate seems so difficult to pursue as to be essentially valueless.

An inductive approach would, in this case, be something as follows. Let us aggregate a sample of UFO reports and examine their characteristics with the objective of establishing beyond some reasonable doubt that the characteristics are thus and so. From there we must try to build a theory which explains those characteristics.

Nearly all science operates in practice by a combination and alternation of inductive and deductive methods and in both statistics as a research tool is generally used. However there are some important differences in statistical method depending upon whether we look at that data or evidence in order to formulate a hypothesis or whether we wish to establish a degree of reliability for the validity of what we hypothesize. Perhaps the commonest misuse of statistics is represented by efforts to do both of these at once.

In statistical language, the expression of hypothesis formation after the fact, after examining the data, is called *a posteriori* hypothesis formation. The erection of a hypothesis before the data are examined is called *a priori* formation. The former follows rather easily as a result of the inductive approach and the latter from the deductive method. *A posteriori* hypothesis formation unless properly tested represents the previously mentioned attempt simultaneously to formulate a hypothesis and establish its significance.

In addition to the difficulties in hypothesis formation presented by the UFO problem, there is another problem which should be discussed. This problem, nearly always a crucial one and not as unique to the UFO

problem as the one just mentioned, is the sampling problem. Granted that some hypothesis be formulated either *a priori* or *a posteriori*, we then must test the hypothesis on a randomly selected sample of data. We cannot enter into a complete discussion of random sample selection here, but must simply point out that if we hope to establish the true statistical significance of a hypothesis the selection of sighting reports cannot be biased either in favor of or against that hypothesis to be tested.

For example, let us suppose that we want to test the hypothesis that UFO sighting reports contain a significant (in some statistical sense) number in which the estimated apparent speed exceeds sonic or aircraft speed. Such an experiment could be set up and a sample of report data gathered on which to test the hypothesis. However, unless great care is used in selecting cases for inclusion in the sample, a non-random component is likely to be encountered. This is because it is very likely that it is precisely *because* the UFO exhibited what to someone was supersonic speed that it is reported and included in UFO files of one sort or another. Such a bias in the sample negates the possibility of a statistically reliable answer to the question embodied in the hypothesis.

The preceding example brings up a very perplexing problem. Just what should constitute the population of UFO reports? Should we include all UFO reports regardless of probable explanation, or just those reports for which no rational explanation can be given? It seems intuitively obvious that an observation which is almost certainly of, for example, Venus should not be included in the population *of UFOs*. But the possible dangers of biasing the sample of reports examined by such intuitive reasoning seem to be serious, to say nothing of the problem of determining the division between known and unknown cases. Again, it seems that the unknown nature of the phenomena poses some serious questions as to the definition of the population and therefore to the kinds of question we might ask of report data.

Some UFO literature has used aggregates of report data to search for "trends" or "patterns," either implicitly or explicitly stated.

The basic assumption seems to have been that trends and patterns in UFO reports might provide information on the nature of the phenomenon. This approach appears to be mostly inductive -- perhaps not surprisingly so in view of the difficulties in the deductive approach in the UFO problem.

There are two important comments on this assumption. The first is that any examination of report data is bound to turn up *some* pattern -- we would be quite surprised it the reports were completely featureless. The second is that, as already mentioned, since the patterns were detected from the sample in hand some procedure for testing the significance of the patterns on independent data samples is necessary.

The Vallees (1966) recommend a search for spatial and temporal patterns in the report data. They report 1) a claimed tendency for report positions in a given calendar day to be located in patterns that can be joined by nets of straight lines (the controversial 'orthoteny' hypothesis), 2) a difference in the diurnal variation of different types of UFO reports, and 3) a 26-month periodicity (adjusted for annual variation) in report data. Only in the first instance do the Vallees report any test as to the statistical significance of the claimed pattern. They establish some basic criteria giving the distribution of the number of points determining straight lines used to join nets of points when the points are randomly distributed in space. They do not report, however, testing the straight line hypothesis on a data sample other than the one used to formulate the orthoteny hypothesis.

For the moment, let us assume that all three features may be tested according to the methodology of statistical hypothesis testing and any one proves significant -- that is, the null hypothesis of
1) a spatially random distribution of daily report locations, or
2) no difference in the diurnal variation of types of sightings, or
3) a temporally random distribution of monthly total number of reports
is rejected at, say, the 95% level. Therefore, we conclude with a risk of 95% that *some* non-random spatial or temporal variation occurs in sighting report data. This 'risk level' is a measure of how confident we can be of rejecting the null hypothesis when it is in reality true. Most statistical tests are of this basic type.

However there is another type of statistical error which is inherent in this type of hypothesis testing which generally speaking should be taken into account. We should (if possible) try to determine what is the risk of accepting the null hypothesis when it is in fact false. Normally this type of error is guarded against by formulating the problem so that the *status quo* is represented by the null hypothesis. The *rationale* for this choice is that it is better to err on the conservative side, since generally the risk of accepting the status quo (null hypothesis) when it is in fact false is higher than the risk of rejecting it when actually true. The complete formulation of the problem in these terms would be an exercise in decision theory. Because of the interest aroused by the UFO problem, both scientific and social interest, it appears that a most interesting and appealing exercise would be an attempt to formulate some problems in terms of decision theory.

Even assuming that the decision problem can be attacked and solved and we accept the rejection of one of the null hypotheses, what have we learned? Obviously we are faced with strong evidence that there is something very peculiar about the distribution in space or time of sighting reports. But the use we could make of this peculiarity in drawing conclusions about the nature of UFOs would be limited because of numerous alternative explanations of a peculiar distribution of reports. Statistical reasoning in this hypothetical situation could tell us that the reports are significantly non-random in their spatial or temporal distribution and that the probability is large that there is something there to investigate, but statistical reasoning could tell us nothing about how to *interpret* this non-randomness. In addition the word 'significance' is used in the statistical sense and has no connotation at all of 'importance.'

A useful analogy here might be the cigarette smoking-lung cancer relationship which has also been a storm center of controversy. The statistical significance of a relationship between the two has been established to be very high and almost everyone accepts the level of

statistical significance as indicative of a relationship. However, this significance in no way proves a *causal* relationship between smoking and lung cancer -- that is merely one of a number of alternative explanations of the statistical result. Most people, in addition, would accept the significance level as evidence that there is certainly something to investigate. The use of statistical evidence to choose what to do next rather than to choose between terminal acts involves decision theory, rather than classical statistical hypothesis testing. This type of analysis has already been mentioned above.

To summarize, the UFO phenomena presents some difficult and challenging problems to statistical methodology. We are dealing with unknown phenomena, at least in part, which is manifested by subjective, qualitative reports from observers with a wide spectrum of ability to report what they see. We cannot place the phenomena in the laboratory to study them and design experiments on them. There are very fundamental problems such as defining the population to be used in statistical studies, and formulating hypotheses about characteristics or report data *a posteriori* and attempting to interpret these as manifestations of unknown phenomena.

The physical scientist conversant with statistics and statistical methodology is likely to come to one of two conclusions about the possibility of productive use of statistics in the UFO problem. Considering the difficulties described above he may conclude that the methodology of statistical analysis does not offer satisfying answers to the important, central questions of the UFO phenomena, and that efforts should be directed at increasing understanding of atmospheric optics, etc. or in attempting to make some measurement of some physical quantity associated with an UFO. Or he might take the position that difficulties of statistical analysis in this instance should not prevent efforts to make analyses, because the risk of throwing away valuable information by ignoring sighting report data should not be overlooked. This position must be taken with some care, however, for he would be taking it as "a last resort and forlorn hope" as Moroney puts it.

The social scientist, on the other hand, might take a different position. Instead of concerning himself with report sightings as a measure of a physical phenomena he might be attracted by the data as a source of information on psychological and social-psychological problems of perception, reporting, etc. We do not regard ourselves as qualified to pursue this point further. Mention of it was made at the beginning of this chapter and additional discussion may be found in Section VI in Chapters 1 and 2.

As a result of considering the problem of the role of statistical analysis of report data in investigating UFO phenomena we conclude that very grave difficulties are present involving rather fundamental aspects of statistical methodology. It is our feeling that little value to the physical sciences will result from "searching" the report data for "significant" features.

We qualify this view in two ways: First, we are not able, of course, to perceive the future and it may be that an innovative worker paying careful attention to the demands of methodology might well produce a study which represents a real increase in knowledge about UFOs. We should in this regard give the decision-theory approach some thought: we should attempt to evaluate the consequences of statistical error of both kinds and to consider the problems posed by question of the "where do we go from here?" type. Second, efforts to investigate UFO *reports* rather than the UFO phenomena seem to offer fertile ground for future study.

Section VII

Appendices

APPENDIX A:

SPECIAL REPORT OF THE USAF SCIENTIFIC ADVISORY BOARD AD HOC COMMITTEE TO REVIEW PROJECT "BLUE BOOK"

MARCH 1966

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Dr. Launor F. Carter
Mr. Jesse Orlansky
Dr. Richard Porter
Dr. Carl Sagan
Dr. Willis H. Ware

SAB SECRETARIAT

Lt Col Harold A. Steiner

SPECIAL
REPORT OF THE
USAF SCIENTIFIC ADVISORY BOARD
AD HOC COMMITTEE TO REVIEW
PROJECT "BLUE BOOK"

MARCH 1966

I. INTRODUCTION

As requested in a memorandum from Major General E. B. LeBailly, Secretary of the Air Force Office of Information, dated 28 September 1965 (Tab A), an SAB Ad Hoc Committee met on 3 February 1966 to review Project "Blue Book". The objectives of the Committee are to review the resources and methods of investigation prescribed by Project "Blue Book" and to advise the Air Force of any improvements that can be made in the program to enhance the Air Force's capability in carrying out its responsibility.

In order to bring themselves up to date, the members of the Committee initially reviewed the findings of previous scientific panels charged with looking into the UFO problem. Particular attention was given to the report of the Robertson panel which was rendered in January 1953. The Committee next heard briefings from the AFSC Foreign Technology Division, which is the cognizant Air Force agency that collates information on UFO sightings and monitors investigations of individual cases. Finally, the Committee reviewed selected case histories of UFO sightings with particular emphasis on those that have not been identified.

II. DISCUSSION

Although about 6% (646) of all sightings (10,147) in the years 1947 through 1965 are listed by the Air Force as "Unidentified", it appears to the Committee that

most of the cases so listed are simply those in which the information available does not provide an adequate basis for analysis. In this connection it is important also to note that no unidentified objects other than those of an astronomical nature have ever been observed during routine astronomical studies, in spite of the large number of observing hours which have been devoted to the sky. As examples of this the Palomar Observatory Sky Atlas contains some 5000 plates made with large instruments with wide field of view; the Harvard Meteor Project of 1954-1958 provided some 3300 hours of observation; the Smithsonian Visual Prairie Network provided 2500 observing hours. Not a single unidentified object has been reported as appearing on any of these plates or been sighted visually in all these observations.

The Committee concluded that in the 19 years since the first UFO was sighted there has been no evidence that unidentified flying objects are a threat to our national security. Having arrived at this conclusion the Committee then turned its attention to considering how the Air Force should handle the scientific aspects of the UFO problem. Unavoidably these are also related to Air Force public relations, a subject on which the Committee is not expert. Thus the recommendations which follow are made simply from the scientific point of view.

III. CONCLUSIONS AND RECOMMENDATIONS

It is the opinion of the Committee that the present Air Force program dealing with UFO sightings has been well organized, although the resources assigned to it (only one officer, a sergeant, and secretary) have been quite limited. In 19 years and more than 10,000 sightings recorded and classified, there appears to be no verified and fully satisfactory evidence of any case that is clearly outside the framework of presently

known science and technology. Nevertheless, there is always the possibility that analysis of new sightings may provide some additions to scientific knowledge of value to the Air Force. Moreover, some of the case records which the Committee looked that were listed as "identified" were sightings where the evidence collected was too meager or too indefinite to permit positive listing in the identified category. Because of this the Committee recommends that the present program be strengthened to provide opportunity for scientific investigation of selected sightings in more detail and depth than has been possible to date.

To accomplish this it is recommended that:

A. Contracts be negotiated with a few selected universities to provide scientific teams to investigate promptly and in depth certain selected sightings of UFO's. Each team should include at least one psychologist, preferably one interested in clinical psychology, and at least one physical scientist, preferably an astronomer or geophysicist familiar with atmospheric physics. The universities should be chosen to provide good geographical distribution, and should be within convenient distance of a base of the Air Force Systems Command (AFSC).

B. At each AFSC base an officer skilled in investigation (but not necessarily with scientific training) should be designated to work with the corresponding university team for that geographical section. The local representative of the Air Force Office of Special Investigations (OSI) might be a logical choice for this.

C. One university or one not-for-profit organization should be selected to coordinate the work of the teams mentioned under A above, and also to make certain of very close communication and coordination with the office of Project Blue Book.

It is thought that perhaps 100 sightings a year might be subjected to this close study, and that possibly an average of 10 man days might be required per sighting so studied. The information provided by such a program might bring to light new facts of scientific value, and would almost certainly provide a far better basis than we have today for decision on a long term UFO program.

The scientific reports on these selected sightings, supplementing the present program of the Project Blue Book office, should strengthen the public position of the Air Force on UFO's. It is, therefore, recommended that:

A. These reports be printed in full and be available on request.

B. Suitable abstracts or condensed versions be printed and included in, or as supplements to, the published reports of Project Blue Book.

C. The form of report (as typified by "Project Blue Book" dated 1 February 1966) be expanded, and anything which might suggest that information is being withheld (such as the wording on page 5 of the above cited reference) be deleted. The form of this report can be of great importance in securing public understanding and should be given detailed study by an appropriate Air Force office.

D. The reports "Project Blue Book" should be given wide unsolicited circulation among prominent members of the Congress and other public persons as a further aid to public understanding of the scientific approach being taken by the Air Force in attacking the UFO problem.

DEPARTMENT OF THE AIR FORCE
WASHINGTON

OFFICE OF THE SECRETARY

MEMORANDUM FOR MILITARY DIRECTOR, SCIENTIFIC ADVISORY BOARD

SUBJECT: Unidentified Flying Objects (UFOs)

In keeping with its air defense role, the Air Force has the responsibility for the investigation of unidentified flying objects reported over the United States. The name of this project is Blue Book (Attachment 1). Procedures for conducting this program are established by Air Force Regulation 200-2 (Attachment 2).

The Air Force has conducted Project Blue Book since 1948. As of 30 June 1965, a total of 9267 reports had been investigated by the Air Force. Of these 9267 reports, 663 cannot be explained.

It has been determined by the Assistant Deputy Chief of Staff/ Plans and Operations that Project Blue Book is a worthwhile program which deserves the support of all staff agencies and major commands and that the Air Force should continue to investigate and analyze all UFO reports in order to assure that such objects do not present a threat to our national security. The Assistant Deputy Chief of Staff/Plans and Operations has determined also that the Foreign Technology Division (FTD) at Wright-Patterson Air Force Base should continue to exercise its presently assigned responsibilities concerning UFOs.

To date, the Air Force has found no evidence that any of the UFO reports reflect a threat to our national security. However, many of the reports that cannot be explained have come from intelligent and technically well qualified individuals whose integrity cannot be doubted. In addition, the reports received officially by the Air Force include only a fraction of the spectacular reports which are publicized by many private UFO organizations.

Accordingly, it is requested that a working scientific panel composed of both physical and social scientists be organized to review Project Blue Book -- its resources, methods, and findings -- and to advise the Air Force as to any improvements that should be made in the program in order to carry out the Air Force's assigned responsibility.

Doctor J. Allen Hynek who is the Chairman of the Dearborn Observatory at Northwestern University is the scientific consultant to Project Blue Book. He has indicated a willingness to work with such a panel in order to place this problem in its proper perspective.

Doctor Hynek has discussed this problem with Doctor Winston R. Markey, the former Air Force Chief Scientist.

E. B. LeBailly

E. B. LeBAILLY
Major General, USAF
Director of Information

2 Attachments
1. Blue Book Report
2. AFR 200-2

AD HOC COMMITTEE ON
UNIDENTIFIED FLYING OBJECTS (UFOs)

AGENDA

Thursday, 3 February 1966

0800	Welcoming Remarks	Commander or Vice Commander, FTD
0805	Introduction	Dr. O'Brien, SAB
0810	The Air Force Problem	Lt Col Spaulding, SAFOI
0830	Briefing on Project Blue Book	Major Quintanilla, FTD
1000	Break	
1015	Review of Selected Case Histories	FTD Staff
1145	Lunch	
1315	Executive and Writing Session	

22 December 1965

SPECIAL
REPORT OF THE USAF SCIENTIFIC ADVISORY BOARD
AD HOC COMMITTEE TO REVIEW PROJECT "BLUE BOOK"

DISTRIBUTION

	SYMBOL	COPIES
Secretary of the Air Force Office of Information	SAFOI	25
Military Director, DCS/R&D	AFRDC	1
Committee Members (1 each) Dr. Brian O'Brien (Chairman) Dr. Launor F. Carter Mr. Jesse Orlansky Dr. Richard Porter Dr. Carl Sagan Dr. Willis H. Ware		6
Commander, Foreign Technology Division		5
DCS/Foreign Technology (AFSC)	SCF	2
Chairman, SAB	AFBSA	1
SAB Secretariat	AFBSA	1

Meeting statistics bearing on this report including all times, dates, places, a listing of persons in attendance and purposes therefor, together with their affiliations and material reviewed and discussed, are available in the SAB Secretariat offices for review by authorized persons or agencies.

APPROVED BY:

Harold A. Steiner

HAROLD A. STEINER, Lt Colonel, USAF
Assistant Secretary
USAF Scientific Advisory Board

AIR FORCE REGULATION
NO. 80-17

DEPARTMENT OF THE AIR FORCE
Washington, D. C. 19 September 1966

Research And Development

UNIDENTIFIED FLYING OBJECTS (UFO)

This regulation establishes the Air Force program for investigating and analyzing UFOs over the United States. It provides for uniform investigative procedures and release of information. The investigations and analyses prescribed are related directly to the Air Force's responsibility for the air defense of the United States. The UFO Program requires prompt reporting and rapid evaluation of data for successful identification. Strict compliance with this regulation is mandatory.

SECTION A—GENERAL PROVISIONS

1. Explanation of Terms. To insure proper and uniform usage of terms in UFO investigations, reports, and analyses, an explanation of common terms follows:

a. *Unidentified Flying Objects.* Any aerial phenomenon or object which is unknown or appears out of the ordinary to the observer.

b. *Familiar or Known Objects/Phenomena.* Aircraft, aircraft lights, astronomical bodies (meteors, planets, stars, comets, sun, moon), balloons, birds fireworks, missiles, rockets, satellites, searchlights, weather phenomena (clouds, contrails, dust devils), and other natural phenomena.

2. Program Objectives. Air Force interest in UFOs is two-fold: to determine if the UFO is a possible threat to the United States and to use the scientific or technical data gained from study of UFO reports. To attain these objectives, it is necesssary to explain or identify the stimulus which caused the observer to report his observation as an unidentified flying object.

a. *Air Defense.* The majority of UFOs reported to the Air Force have been conventional or familiar objects which present no threat to our security.

(1) It is possible that foreign countries may develop flying vehicles of revolutionary configuration or propulsion.

(2) Frequently, some alleged UFOs are determined to be aircraft. Air Defense Command (ADC) is responsible for identification

This regulation supersedes AFR 200-2, 20 July 1962
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of aircraft. Except as aircraft are determined to be the stimulus for a UFO report, aircraft are not to be reported under the provisions of this regulation.

b. *Technical and Scientific.* The Air Force will analyze reports of UFOs submitted to it to attain the program objectives. In this connection these facts are of importance:

(1) The need for further scientific knowledge in geophysics, astronomy, and physics of the upper atmosphere which may be provided by study and analysis of UFOs and similar aerial phenomena.

(2) The need to report all pertinent factors that have a direct bearing on scientific analysis and conclusions of UFO sightings.

(3) The need and the importance of complete case information. Analysis has explained all but a small percentage of the sightings which have been reported to the Air Force. The ones that have not been explained are carried statistically as "unidentified." Because of the human factors involved and because analysis of a UFO sighting depends primarily on a personal impression and interpretation by the observer rather than on scientific data or facts obtained under controlled conditions, the elimination of of all unidentifeds is improbable. However, if more immediate, detailed, and objective data on the unidentifieds had been available and promptly reported, perhaps these, too, could have been identified.

3. Program Responsibilities:

a. *Program Monitor.* The Deputy Chief of Staff, Research and Development, is responsible for the overall program, evaluation of investigative procedures, and the conduct of separate scientific investigations.

b. *Resources.* The Air Force Systems Command will support the program with current resources within the Foreign Technology Division (FTD) at Wright-Patterson Air Force Base, Ohio, to continue the Project Blue Book effort. Other AFSC resources normally used by FTD for this effort will continue to be made available.

c. *Investigation.* Each commander of an Air Force base will provide a UFO investigative capability. When notice of a UFO sighting is received, an investigation will be implemented to determine the stimulus for the sighting. An Air Force base receiving the notice of a UFO sighting may not be the base nearest the locale of the sighting. In that event, the reported UFO sighting will be referred to the Air Force base nearest the sighting for action.

EXCEPTIONS: FTD at Wright-Patterson Air Force Base, Ohio, independently or with the help of pertinent Air Force activities, may conduct any other investigation to conclude its analysis or findings. HQ USAF may arrange for separate investigations.

d. *Analysis.* FTD will:

(1) Analyze and evaluate all information and evidence reported to bases on those UFOs which are not identified at the base level.

(2) Use other Government agencies, private industrial companies, and contractor personnel to assist in analyzing and evaluating UFO reports, as necesssary.

e. *Findings.* FTD, Wright-Patterson AFB, Ohio, will prepare a final case report on each sighting reported to it after the data have been properly evaluated. If the final report is deemed significant, FTD will send the report of its findings to AFSC (SCFA), Andrews AFB, Wash DC 20331, which will send a report to HQ USAF (AFRDC), Wash DC 20330.

f. *Cooperation.* All Air Force activities will cooperate with UFO investigators to insure that pertinent information relative to investigations of UFO sightings are promptly obtained. When feasible, this will include furnishing air or ground transportation and other assistance.

SECTION B—PUBLIC RELATIONS, INFORMATION, CONTACTS, AND RELEASES

4. Response to Public Interest. The Secretary of the Air Force, Office of Information (SAF-OI), maintains contact with the public and the news media on all aspects of the UFO program and related activities. Private individuals or organizations desiring Air Force interviews, briefings, lectures, or private discussions on UFOs will be instructed to direct their requests to SAF-OI. Air Force members not officially connected with UFO investigations covered by this regulation will refrain from any action or comment on UFO reports which may mislead or cause the public to construe these opinions as official Air Force findings

5. Releasing Information. SAF-OI is the agency responsible for releasing information to the public and to the news media.

a. *Congressional and Presidential Inquiries.* The Office of Legislative Liaison will:

(1) With the assistance of SAF-OI, an-

swer all Congressional and Presidential queries regarding UFOs forwarded to the Air Force.

(2) Process requests from Congressional sources in accordance with AFR 11-7.

b. *SAF-OI will:*

(1) Respond to correspondence from individuals requesting information on the UFO Program and evaluations of sightings.

(2) Release information on UFO sightings and results of investigations to the general public.

(3) Send correspondence queries which are purely technical and scientific to FTD for information on which to base a reply.

c. *Exceptions.* In response to local inquiries regarding UFOs reported in the vicinity of an Air Force base, the base commander may release information to the news media or the public after the sighting has been positively identified. If the stimulus for the sighting is difficult to identify at the base level, the commander may state that the sighting is under investigation and conclusions will be released by SAF-OI after the investigation is completed. The commander may also state that the Air Force will review and analyze the results of the investigation. Any further inquiries will be directed to SAF-OI.

SECTION C—PREPARING AND SUBMITTING REPORTS

6. General Information:

a. The Deputy Chief of Staff, Research and Development, USAF and the ADC have a direct and immediate interest in UFOs reported within the US. All Air Force activities will conduct UFO investigations to the extent necessary for reporting action (see paragraphs 9, 10, 11, and 12). Investigation may be carried beyond this point when the preparing officer believes the scientific or public relations aspect of the case warrants further investigation. In this case, the investigator will coordinate his continued investigation with FTD.

b. Paragraph 7 will be used as a guide for screenings, investigations, and reportings. Paragraph 11 is an outline of the reporting format.

c. Inquiries should be referred to SAF-OI (see paragraph 5).

d. If possible, an individual selected as a UFO investigator should have a scientific or technical background and experience as an investigator.

e. Reports required by this regulation are excluded from assignment of a reports control symbol in accordance with paragraph 3k, AFR 300-5.

7. Guidance in Preparing Reports. The usefulness of a UFO report depends largely on accuracy, timeliness, skill and resourcefulness of the person who receives the initial information and makes the report. Following are aids for screening, evaluating and reporting sightings:

a. Activities receiving initial reports of aerial objects and phenomena will screen the information to determine if the report concerns a valid UFO as defined in paragraph 1a. Reports not falling within that definition do not require further action. Aircraft flares, jet exhausts, condensation trails, blinking or steady lights observed at night, lights circling near airports and airways, and other aircraft phenomena should not be reported as they do not fall within the definition of a UFO.

EXCEPTION: Reports of known objects will be made to FTD when this information originally had been reported by local news media as a UFO and the witness has contacted the Air Force. (Do NOT solicit reports.) News releases should be included as an attachment with the report (see paragraph 8c).

b. Detailed study will be made of the logic, consistency, and authenticity of the observer's report. An interview with the observer, by persons preparing the report, is especially valuable in determining the reliability of the source and the validity of the information. Factors for particular attention are the observer's age, occupation, and education, and whether he has a technical or scientific background. A report that a witness is completely familiar with certain aspects of a sighting should indicate specific qualifications to substantiate such familiarity.

c. The following procedures will assist the investigating officer in completing the report and arriving at a conclusion as required in paragraph 11.

(1) When feasible, contact local aircraft control and warning (ACW) units, and pilots and crews of aircraft aloft at the time and place of sighting. Contact any persons or organizations that may have additional data on the UFO or can verify evidence—visual, electronic, or other.

(2) Consult military or civilian weather forecasters for data on tracks of weather

balloons or any unusual meteorological activity that may have a bearing on the stimulus for the UFO.

(3) Consult navigators and astronomers in the area to determine if any astronomical body or phenomenon might account for the sighting.

(4) Consult military and civilian tower operators, air operations units, and airlines to determine if the sighting could have been an aircraft. Local units of the Federal Aviation Agency (FAA) can be of assistance in this regard.

(5) Consult persons who may know of experimental aircraft of unusual configuration, rocket and guided missile firings, or aerial tests in the area.

(6) Consult local and State police, county sheriffs, forest rangers, and other civil officials who may have been in the area at the time of the sighting or have knowledge of other witnesses.

8. Transmittal of Reports:

a. *Timeliness.* Report all information on UFOs promptly. Electrical transmission with a "Priority" precedence is authorized.

b. *Submission of Reports.* Submit multiple-addressed electrical reports to:

(1) ADC.

(2) Nearest Air Division (Defense).

(3) FTD WPAFB. (First line of text: FOR TDETR.)

(4) CSAF. (First line of text: FOR AFRDC.)

(5) OSAF. (First line of text: FOR SAF-OI.)

c. *Written Reports.* In the event follow-up action requires a letter report, send it to FTD (TDETR), Wright-Patterson AFB, Ohio 45433. FTD will send the reports to interested organizations in the US and to SAF-OI if required.

d. *Reports from Civilians.* Advise civilians to report UFOs to the nearest Air Force base.

e. *Negative or Inapplicable Data.* If specific information is lacking, refrain from using the words "negative" or "unidentified" unless all logical leads to obtain the information outlined in paragraph 11 have been exhausted. For example, the information on weather conditions in the area, as requested in paragraph 11g, is obtainable from the local military or civilian weather facility. Use the phrase "not applicable (NA)" only when the question really does not apply to the sighting under investigation.

10. Comments of Investigating Officer. This officer will make an initial analysis and comment on the possible cause or identity of the stimulus in a supporting statement. He will make every effort to obtain pertinent items of information and to test all possible leads, clues, and hypotheses. The investigating officer who receives the initial report is in a better position to conduct an on-the-spot survey and follow-up than subsequent investigative personnel and analysts who may be far removed from the area and who may arrive too late to obtain vital data or information necessary for firm conclusions. The investigating officer's comments and conclusions will be in the last paragraph of the report submitted through channels. The reporting official will contact FTD (Area Code 513, 257-0916 or 257-6678) for verbal authority to continue investigations.

11. Basic Reporting Data and Format. Show the abbreviation "UFO" at the beginning of the text of all electrical reports and in the subject of any follow-up written reports. Include required data in all electrical reports, in the order shown below:

a. Description of the Object(s):

(1) Shape.

(2) Size compared to a known object.

(3) Color.

(4) Number.

(5) Formation, if more than one.

(6) Any discernible features or details.

(7) Tail, trail, or exhaust, including its size.

(8) Sound.

(9) Other pertinent or unusual features.

b. Description of Course of Object(s):

(1) What first called the attention of observer(s) to the object(s)?

(2) Angle of elevation and azimuth of object(s) when first observed. (Use theodolite or compass measurement if possible.)

(3) Angle of elevation of object(s) upon disappearance. (Use theodolite or compass measurement if possible.)

(4) Description of flight path and maneuvers of object(s). (Use elevations and azimuth, not altitude.)

(5) How did the object(s) disappear? (Instantaneously to the North, for example.)

(6) How long were the object(s) visible? (Be specific—5 minutes, 1 hour, etc.)

c. Manner of Observation:

(1) Use one or any combination of the following items: Ground-visual, air-visual, ground-electronic, air-electronic. (If electronic, specify type of radar.)

(2) Statement as to optical aids (tele-

scopes, binoculars, etc.) used and description thereof.

(3) If the sighting occurred while airborne, give type of aircraft, identification number, altitude, heading, speed, and home station.

d. Time and Date of Sighting:

(1) Greenwich date-time group of sighting and local time.

(2) Light conditions (use one of the following terms: Night, day, dawn, dusk).

e. Location of Observer(s). Give exact latitude and longitude coordinates of each observer, and/or geographical position. In electrical reports, give a position with reference to a known landmark in addition to the coordinates. For example, use "2 mi N of Deeville"; "3 mi SW of Blue Lake," to preclude errors due to teletype garbling of figures.

f. Identifying Information on Observer(s):

(1) Civilian—Name, age, mailing address, occupation, education and estimate of reliability.

(2) Military—Name, grade, organization, duty, and estimate of reliability.

g. Weather and Winds-Aloft Conditions at Time and Place of Sightings:

(1) Observer(s) account of weather conditions.

(2) Report from nearest AWS or US Weather Bureau Office of wind direction and velocity in degrees and knots at surface, 6,000', 10,000', 16,000', 20,000', 30,000', 50,000', and 80,000', if available.

(3) Ceiling.

(4) Visibility.

(5) Amount of cloud cover.

(6) Thunderstorms in area and quadrant in which located.

(7) Vertical temperature gradient.

h. Any other unusual activity or condition, meteorological, astronomical, or otherwise, that might account for the sighting.

i. Interception or identification action taken (such action is authorized whenever feasible and in compliance with existing air defense directives).

j. Location, approximate altitude, and general direction of flight of any air traffic or balloon releases in the area that might possibly account for the sighting.

k. Position title and comments of the preparing officer, including his preliminary analysis of the possible cause of the sightings(s). (See paragraph 10.)

12. Reporting Physical Evidence:

a. *Photographic:*

(1) Still Photographs. Forward the original negative to FTD (TDETR), Wright-Patterson AFB, Ohio 45433, and indicate the place, time, and date the photograph was taken.

(2) Motion Pictures. Obtain the *original* film. Examine the film strip for apparent cuts, alterations, obliterations, or defects. In the report comment on any irregularities, particularly in films received from other than official sources.

(3) Supplemental Photographic Information. Negatives and prints often are insufficient to provide certain valid data or permit firm conclusions. Information that aids in plotting or in estimating distances, apparent size and nature of object, probable velocity, and movements includes:

(a) Type and make of camera.

(b) Type, focal length, and make of lens.

(c) Brand and type of film.

(d) Shutter speed used.

(e) Lens opening used; that is, "f" stop.

(f) Filters used.

(g) Was tripod or solid stand used.

(h) Was "panning" used.

(i) Exact direction camera was pointing with relation to true North, and its angle with respect to the ground.

(4) Other Camera Data. If supplemental information is unobtainable, the minimum camera data required are the type of camera, and the smallest and largest "f" stop and shutter speed readings of the camera.

(5) Radar. Forward two copies of each still camera photographic print. Title radarscope photographic prints per AFR 95-7. Classify radarscope photographs per AFR 205-1.

NOTE: If possible, develop film before forwarding. Mark undeveloped film clearly to indicate this fact, to avoid destruction by exposure through mail channels to final addressees.

b. *Material.* Air Force echelons receiving suspected or actual UFO material will safeguard it to prevent any defacing or alterations which might reduce its value for intelligence examination and analysis.

c. *Photographs, Motion Pictures, and Negatives Submitted by Individuals.* Individuals often submit photographic and motion picture material as part of their UFO reports. All original material submitted will be returned to the individual after completion of necessary studies, analysis, and duplication by the Air Force.

BY ORDER OF THE SECRETARY OF THE AIR FORCE

J. P. McCONNELL
General, U.S. Air Force
Chief of Staff

OFFICIAL

R. J. PUGH
Colonel, USAF
Director of Administrative Services

CHANGE 2, AFR 80-17

AIR FORCE REGULATION
NO. 80–17(C2)

DEPARTMENT OF THE AIR FORCE
Washington, *30 September 1968*

Research and Development

UNIDENTIFIED FLYING OBJECTS (UFO)

AFR 80-17, 19 September 1966, and change 1, 26 October 1967, are changed as follows:

8b(3). FTD WPAFB. (First line of text: FOR TDPT (UFO).)

8b(6). Delete.

BY ORDER OF THE SECRETARY OF THE AIR FORCE

OFFICIAL

J. P. McCONNELL, *General, USAF*
Chief of Staff

JOHN F. RASH, *Colonel, USAF*
Director of Administrative Services

DISTRIBUTION: S

AIR FORCE REGULATION
NO. 80-17(C1)

DEPARTMENT OF THE AIR FORCE
Washington, *26 October 1967*

Research and Development

UNIDENTIFIED FLYING OBJECTS (UFO)

AFR 80-17, 19 September 1966, is changed as follows:

★**3c.** *Investigation.* Each commander of an Air Force base within the United States will provide a UFO . . . sighting for action.

3c. *EXCEPTIONS:* FTD at Wright-Patterson . . . for separate investigations. The University of Colorado, under a research agreement with the Air Force, will conduct a study of UFOs. This program (to run approximately 15 months) will be conducted independently and without restrictions. The university will enlist the assistance of other conveniently located institutions that can field investigative teams. *All* UFO reports will be submitted to the University of Colorado, which will be given the fullest cooperation of all UFO Investigating Officers. Every effort will be made to keep all UFO reports unclassified. However, if it is necessary to classify a report because of method of detection or other factors not related to the UFO, a separate report including all possible information will be sent to the University of Colorado.

★**6a.** The Deputy Chief of Staff, . . . reported within the United States. All Air Force activities within the United States will conduct UFO . . . investigation with FTD.

8b(6). University of Colorado, Boulder CO 80302, Dr. Condon. (Mail copy of message form.)

★**8c.** *Reports.* If followup action is required on electrically transmitted reports, prepare an investigative report on AF Form 117, "Sighting of Unidentified Phenomena Questionnaire," which will be reproduced locally on 8" x 10½" paper in accordance with attachment 1 (9 pages). Send the completed investigative report to FTD (TDETR), Wright-Patterson AFB OH 45433. FTD will send the reports to interested organizations in the United States and to Secretary of the Air Force (SAFOI), Wash DC 20330, if required.

8e. Negative or Inapplicable Data. Renumber as paragraph 9.

11k. Position title, name, rank, official address, telephone area code, office and home telephone, and comments of the preparing officer, including his preliminary analysis of the possible cause of the sighting. (See paragraph 10.)

BY ORDER OF THE SECRETARY OF THE AIR FORCE

OFFICIAL

J. P. McCONNELL, *General, USAF*
Chief of Staff

R. J. PUGH, *Colonel, USAF*
Director of Administrative Services

1 Attachment
AF Form 117, "Sighting of Unidentified Phenomena Questionnaire"

This regulation supersedes AFR 80-17A, 8 November 1966.
OPR: AFRDDG
DISTRIBUTION: S

SIGHTING OF UNIDENTIFIED PHENOMENA QUESTIONNAIRE	BUDGET BUREAU APPROVAL NUMBER 21-R258

THIS QUESTIONNAIRE HAS BEEN PREPARED SO THAT YOU CAN GIVE THE U.S. AIR FORCE AS MUCH INFORMATION AS POSSIBLE CONCERNING THE UNIDENTIFIED PHENOMENON THAT YOU HAVE OBSERVED. PLEASE TRY TO ANSWER ALL OF THE QUESTIONS. THE INFORMATION YOU GIVE WILL BE USED FOR RESEARCH PURPOSES YOUR NAME WILL NOT BE USED IN CONNECTION WITH ANY OF YOUR STATEMENTS OR CONCLUSIONS WITHOUT YOUR PERMISSION. RETURN TO AIR FORCE BASE INVESTIGATOR FOR FORWARDING TO FTD (TDETR), WRIGHT-PATTERSON AFB, OHIO 45433, IAW AFR 80-17. *(IF ADDITIONAL SHEETS ARE NEEDED FOR NARRATIVE OR SKETCHES ATTACH SECURELY TO THIS FORM OR ANNOTATE WITH YOUR NAME FOR IDENTIFICATION.)*

1. WHEN DID YOU SEE THE PHENOMENON?

DAY________ MONTH ________ YEAR ________

2. WHAT TIME DID YOU FIRST SIGHT THE PHENOMENON?

HOUR ________ MINUTES ________ [ ] A.M. [ ] P.M.

3. WHAT TIME DID YOU LAST SIGHT THE PHENOMENON?

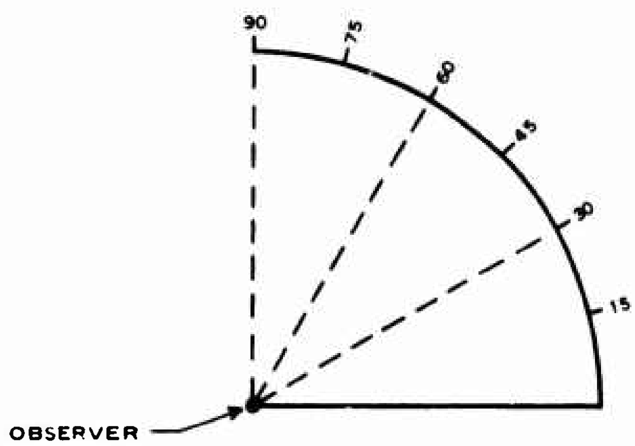
HOUR ________ MINUTES ________ [ ] A.M. [ ] P.M.

4. TIME/ZONE [ ] DAYLIGHT SAVINGS [ ] STANDARD

[ ] EASTERN [ ] CENTRAL [ ] MOUNTAIN [ ] PACIFIC [ ] OTHER

5. WHERE WERE YOU WHEN YOU SAW THE PHENOMENON? IF IN CITY, GIVE THE NEAREST STREET ADDRESS AND INDICATE ON A HAND DRAWN MAP WHERE YOU WERE STANDING WITH REFERENCE TO THE ADDRESS. IF IN THE COUNTRY, IDENTIFY THE HIGHWAY YOU WERE ON OR NEAR AND TRY TO FIX A DISTANCE AND DIRECTION FROM SOME RECOGNIZABLE LANDMARK.

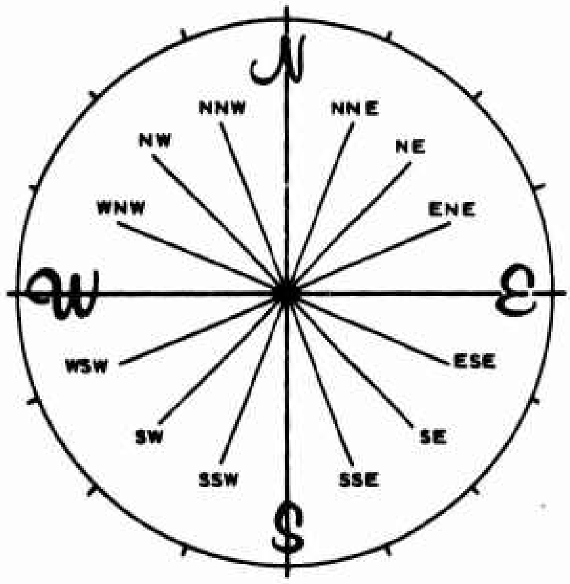
6. IMAGINE YOU ARE AT THE POINT SHOWN IN THE SKETCH. PLACE AN "A" ON THE CURVED LINE TO SHOW HOW HIGH THE PHENOMENON WAS ABOVE THE HORIZON, OR SKYLINE, WHEN FIRST SEEN. PLACE A "B" ON THE SAME CURVED LINE TO SHOW HOW HIGH ABOVE THE HORIZON THE PHENOMENON WAS WHEN LAST SEEN.



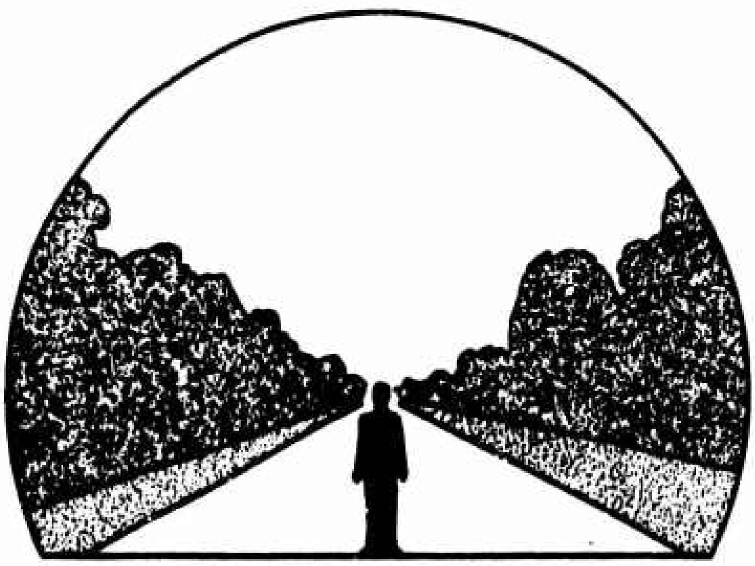
AF FORM AUG 67 117

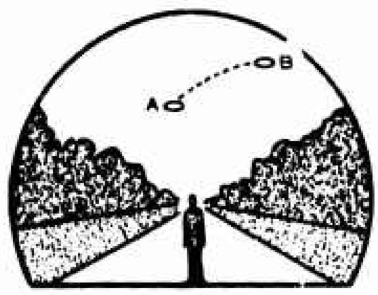
Attachment 1
(Becomes Attachment 1 to AFR 80-17)

6A. NOW IMAGINE YOU ARE AT THE CENTER OF THE COMPASS ROSE. PLACE AN "A" ON THE COMPASS TO INDICATE THE DIRECTION TO THE PHENOMENON WHEN FIRST SEEN. PLACE A "B" ON THE COMPASS TO INDICATE THE DIRECTION TO THE PHENOMENON WHEN LAST SEEN.



7. IN THE SKETCH BELOW, PLACE AN "A" AT THE POSITION OF THE PHENOMENON WHEN FIRST SEEN, AND A "B" AT THE POSITION OF THE PHENOMENON WHEN LAST SEEN. CONNECT THE "A" AND "B" WITH A LINE TO APPROXIMATE THE MOVEMENT OF THE PHENOMENON BETWEEN "A" AND "B". THAT IS, SCHEMATICALLY SHOW WHETHER THE MOVEMENT APPEARED TO BE STRAIGHT, CURVED OR ZIG-ZAG. REFER TO SMALLER SKETCH AS AN EXAMPLE OF HOW TO COMPLETE THE LARGER SKETCH.





Attachment 1
(Becomes Attachment 1 to AFR 80-17)

8.	WHERE WERE YOU WHEN YOU SAW THE PHENOMENON? *(Check appropriate blocks.)*		
	OUTDOORS		IN BUSINESS SECTION OF CITY
	IN BUILDING		IN RESIDENTIAL SECTION OF CITY
	IN CAR ☐ AS DRIVER ☐ AS PASSENGER		IN OPEN COUNTRYSIDE
	IN BOAT		NEAR AIRFIELD
	IN AIRPLANE ☐ AS PILOT ☐ AS PASSENGER		FLYING OVER CITY
	OTHER		FLYING OVER OPEN COUNTRY
			OTHER

A. IF YOU WERE IN A VEHICLE, COMPLETE THE FOLLOWING:

WHAT DIRECTION WERE YOU MOVING?				HOW FAST WERE YOU MOVING?
	NORTH		EAST	
	SOUTH		WEST	DID YOU STOP ANYTIME WHILE OBSERVING THE PHENOMENON?
	NORTHEAST		SOUTHEAST	
	NORTHWEST		SOUTHWEST	☐ YES ☐ NO

EXPLAIN WHETHER SUCH MOVEMENT AFFECTS YOUR SKETCHES IN ITEMS 5 AND 6.

DESCRIBE TYPE OF VEHICLE YOU WERE IN AND TYPE OF ROAD, TERRAIN OR BODY OF WATER YOU TRAVERSED DURING THE SIGHTING. STATE WHETHER WINDOWS OR CONVERTIBLE TOP WERE UP OR DOWN.

HOW MUCH OTHER TRAFFIC WAS THERE?

DID YOU NOTICE ANY AIRPLANES? ☐ YES ☐ NO. IF "YES," DESCRIBE WHEN THEY WERE IN SIGHT RELATIVE TO THE TIME OF SIGHTING THE PHENOMENON AND WHERE THEY WERE IN THE SKY RELATIVE TO THE POSITION OF THE PHENOMENON.

9.	HOW LONG WAS THE PHENOMENON IN SIGHT?			
LENGTH OF TIME		CERTAIN OF TIME		NOT VERY SURE
		FAIRLY CERTAIN		JUST A GUESS

HOW WAS TIME DETERMINED?

WAS THE PHENOMENON IN SIGHT CONTINUOUSLY? ☐ YES ☐ NO. IF "NO," INDICATE WHETHER THIS IS DUE TO YOUR MOVEMENT OR THE BEHAVIOR OF THE PHENOMENON, AND DESCRIBE SUCH MOVEMENT OR BEHAVIOR. INDICATE DISAPPEARANCES ON PREVIOUS SKETCHES.

Attachment 1
(Becomes Attachment 1 to AFR 80-17)

10. IF THERE WERE MORE THAN ONE PHENOMENON, HOW MANY WERE THERE? DRAW A PICTURE TO SHOW HOW THEY WERE ARRANGED. DID THIS ARRANGEMENT CHANGE DURING THE SIGHTING?

11. CONDITIONS *(Check appropriate blocks.)*

A.	SKY	B.	WEATHER		
	DAY		CUMULUS CLOUDS *(Low fluffy)*		FOG OR MIST
	TWILIGHT		CIRRUS CLOUDS *(High fleecy or Herring-bone)*		HEAVY RAIN
	NIGHT				LIGHT RAIN OR DRIZZLE
	CLEAR		NIMBUS CLOUDS *(Rain)*		HAIL
	PARTLY CLOUDY		CUMULONIMBUS CLOUDS *(Thunderstorms)*		SNOW OR SLEET
	COMPLETELY OVERCAST				UNKNOWN
			HAZE OR SMOG		NONE OF THE ABOVE

C. IF THE SIGHTING WAS AT TWILIGHT OR NIGHT, WHAT DID YOU NOTICE ABOUT THE STARS AND MOON?

(1)	STARS	(2)	MOON		
	NONE		BRIGHT MOONLIGHT		NO MOONLIGHT
	A FEW		MOON WITH HALO		UNKNOWN
	MANY		MOON HIDDEN BY CLOUDS		
	UNKNOWN		PARTIAL *(New or quarter)*		

D. IF SIGHTING WAS IN DAYLIGHT, WAS THE SUN VISIBLE? ☐ YES ☐ NO. IF "YES," WHERE WAS THE SUN AS YOU FACED THE PHENOMENON?

	IN FRONT OF YOU		TO YOUR RIGHT		OVERHEAD *(Near noon)*
	IN BACK OF YOU		TO YOUR LEFT		UNKNOWN

E. SPECIFY THE MAJOR SOURCE OF ILLUMINATION PRESENT DURING THE SIGHTING, SUCH AS THE SUN, HEADLIGHTS OR STREET LAMP, ETC. FOR TERRESTRIAL ILLUMINATION, SPECIFY DISTANCE TO LIGHT SOURCE.

12. GIVE A BRIEF DESCRIPTION OF THE PHENOMENON, INDICATING WHETHER IT APPEARED DARK OR LIGHT, WHETHER IT REFLECTED LIGHT OR WAS SELF-LUMINOUS AND WHAT COLORS YOU NOTICED. DESCRIBE YOUR IMPRESSION OF WHETHER IT WAS SOLID OR TRANSPARENT, WHETHER EDGES WERE SHARP OR FUZZY. DESCRIBE THE SHAPE OR INDICATE IF IT APPEARED AS A POINT OF LIGHT. INDICATE COMPARISONS WITH OTHER OBSERVED OBJECTS, LIKE STARS, A LIGHT OR OTHER OBJECT IN YOUR FIELD OF VIEW.

Attachment 1
(Becomes Attachment 1 to AFR 80-17)

13. DID THE PHENOMENON	YES	NO	UNKNOWN
MOVE IN A STRAIGHT LINE?			
STAND STILL AT ANYTIME?			
SUDDENLY SPEED UP AND RUN AWAY?			
BREAK UP IN PARTS AND EXPLODE?			
CHANGE COLOR?			
GIVE OFF SMOKE?			
CHANGE BRIGHTNESS?			
CHANGE SHAPE?			
FLASH OR FLICKER?			
DISAPPEAR AND REAPPEAR?			
SPIN LIKE A TOP?			
MAKE A NOISE?			
FLUTTER OR WOBBLE?			

14. WHAT DREW YOUR ATTENTION TO THE PHENOMENON?

A. HOW DID IT FINALLY DISAPPEAR?

B. DID THE PHENOMENON MOVE BEHIND OR IN FRONT OF SOMETHING, LIKE A CLOUD, TREE, OR BUILDING AT ANY TIME?
[ ] YES [ ] NO. IF "YES," DESCRIBE.

Attachment 1
(Becomes Attachment 1 to AFR 80-17)

15. DRAW A PICTURE THAT WILL SHOW THE SHAPE OF THE PHENOMENON. INCLUDE AND LABEL ANY DETAILS THAT MIGHT HAVE APPEARED AS WINGS OR PROTRUSIONS, AND INDICATE EXHAUST OR VAPOR TRAILS. INDICATE BY AN ARROW THE DIRECTION THE PHENOMENON WAS MOVING.

16. WHAT WAS THE ANGULAR SIZE? HOLD A MATCH AT ARM'S LENGTH IN FRONT OF A KNOWN OBJECT, SUCH AS A STREET LAMP OR THE MOON. NOTE HOW MUCH OF THE OBJECT IS COVERED BY THE HEAD OF THE MATCH. NOW IF YOU HAD BEEN ABLE TO PERFORM THIS EXPERIMENT AT THE TIME OF THE SIGHTING, ESTIMATE WHAT FRACTION OF THE PHENOMENON WOULD HAVE BEEN COVERED BY THE MATCH HEAD.

17. DID YOU OBSERVE THE PHENOMENON THROUGH ANY OF THE FOLLOWING? INCLUDE INFORMATION ON MODEL, TYPE, FILTER, LENS PRESCRIPTION OR OTHER APPLICABLE DATA.

	EYEGLASSES		CAMERA VIEWER
	SUNGLASSES		BINOCULARS
	WINDSHIELD		TELESCOPE
	SIDE WINDOW OF VEHICLE		THEODOLITE
	WINDOWPANE		OTHER

A. DO YOU ORDINARILY WEAR GLASSES? ☐ YES ☐ NO

B. DO YOU USE READING GLASSES? ☐ YES ☐ NO

18. WHAT WAS YOUR IMPRESSION OF THE SPEED OF THE PHENOMENON? GIVE ESTIMATE OF SPEED ______

19. WHAT WAS YOUR IMPRESSION OF THE DISTANCE OF THE PHENOMENON? GIVE ESTIMATE OF DISTANCE ______.

20. IN ORDER THAT WE MAY OBTAIN AS CLEAR A PICTURE AS POSSIBLE OF WHAT YOU SAW, DESCRIBE IN YOUR OWN WORDS A COMMON OBJECT OR OBJECTS WHICH, WHEN PLACED IN THE SKY, SIMILAR TO WHERE YOU NOTED THE PHENOMENON, WOULD BEAR SOME RESEMBLANCE TO WHAT YOU SAW. DESCRIBE SIMILARITIES AND DIFFERENCES BETWEEN THE COMMON OBJECT AND WHAT YOU SAW.

21. DID YOU NOTICE ANY ODOR, NOISE, OR HEAT EMANATING FROM THE PHENOMENON OR ANY EFFECT ON YOURSELF, ANIMALS OR MACHINERY IN THE VICINITY? ☐ YES ☐ NO. IF "YES," DESCRIBE.

A. DID THE PHENOMENON DISTURB THE GROUND OR LEAVE ANY PHYSICAL EVIDENCE. ☐ YES ☐ NO. IF "YES," DESCRIBE.

22. HAVE YOU EVER SEEN THIS OR A SIMILAR PHENOMENON BEFORE? ☐ YES ☐ NO. IF "YES," GIVE DATE AND LOCATION.

23. WAS ANYONE WITH YOU AT THE TIME YOU SAW THE PHENOMENON? ☐ YES ☐ NO. IF "YES," DID THEY SEE IT TOO? ☐ YES ☐ NO.

A. LIST THEIR NAMES AND ADDRESSES

24. GIVE THE FOLLOWING INFORMATION ABOUT YOURSELF

LAST NAME, FIRST NAME, MIDDLE NAME

ADDRESS *(Street, City, State and Zip Code)*

TELEPHONE *(Area code and number)*	AGE		MALE		FEMALE

INDICATE ADDITIONAL INFORMATION INCLUDING OCCUPATION AND ANY EXPERIENCE WHICH MAY BE PERTINENT.

25 WHEN AND TO WHOM DID YOU REPORT THAT YOU HAD SIGHTED THIS PHENOMENON?

NAME ____________ DAY ______ MONTH ________ YEAR ______

26 DATE YOU COMPLETED THIS QUESTIONNAIRE.

DAY ______ MONTH ________ YEAR ______

27. INFORMATION WHICH YOU FEEL IS PERTINENT BUT WHICH IS NOT ADEQUATELY COVERED IN THIS QUESTIONNAIRE. ALTERNATIVELY PROVIDE A NARRATIVE EXPLANATION OF THE SIGHTING.

Attachment 1
(Becomes Attachment 1 to AFR 80-17)

CHANGE **AFR 80-17A**

AIR FORCE REGULATION
NO. 80-17A

DEPARTMENT OF THE AIR FORCE
Washington, 8 November 1966

Research and Development

UNIDENTIFIED FLYING OBJECTS (UFO)

AFR 80-17, 19 September 1966, is changed as follows:

3c. *EXCEPTIONS:* FTD at Wright-Patterson . . . for separate investigations. The University of Colorado will, under a research agreement with the Air Force, conduct a study of UFOs. This program (to run approximately 15 months) will be conducted independently and without restrictions. The university will enlist the assistance of other conveniently located institutions that can field investigative teams. *All* UFO reports will be submitted to the University of Colorado, which will be given the fullest cooperation of all UFO Investigating Officers. Every effort will be made to keep all UFO reports unclassified. However, if it is necessary to classify a report because of method of detection or other factors not related to the UFO, a separate report including all possible information will be sent to the University of Colorado.

8b(6). University of Colorado, Boulder, Colorado 80302, ATTN: Dr. Condon. (Mail copy of message form.)

8e. Negative or Inapplicable Data. Renumber as paragraph 9.

11k. Position title, name, rank, official address, telephone area code, office and home phone, and comments of the preparing officer including his preliminary analysis of the possible cause of the sighting(s). (See paragraph 10.)

BY ORDER OF THE SECRETARY OF THE AIR FORCE

OFFICIAL

J. P. McCONNELL
General, U. S. Air Force
Chief of Staff

R. J. PUGH
Colonel, USAF
Director of Administrative Services

DISTRIBUTION: S

APPENDIX C: PRESENTATION AT ARIZONA ACADEMY OF SCIENCE MEETING, 29 APRIL 1967, BY GERARD KUIPER, LUNAR AND PLANETARY LABORATORY, UNIVERSITY OF ARIZONA

It is difficult to summarize adequately the very complex set of problems posed by the UFO reports. I think that Dr. McDonald is performing a service to science and the country in attempting to raise the standards of reporting and analysis; but I would differ with him on several points of emphasis.

My own involvement with UFO reports dates back to 1947 when they first became popular. I was then Director of the University of Chicago's Yerkes Observatory in Southern Wisconsin, and the Chicago Daily News and other newspapers contacted me frequently for my evaluation as reports were received from the wire services. I was also intermittently teaching at Chicago on Campus and approached by students who had made puzzling observations of their own. These latter reports were usually disposed of rather easily. Several of them were related to observations of the planet Jupiter seen around 4 AM between passing clouds. I also made a UFO "observation" of my own! It occurred at the McDonald Observatory, in daytime, while I was observing the planet Venus with the 82-inch telescope. I was amazed to see in the daytime sky a number of objects, almost stellar in appearance, with the approximate brightness of Venus. Quick focal measurements with the telescope's finders established that these objects were a few hundred feet above the observatory and moved approximately with the direction and velocity of the wind. They turned out to be spiders floating over the Rocky Mountains on their

webs, causing bright star-like diffraction images when seen almost in the direction of the sun.

I also learned first hand of reports circulating in Southern California during visits to Mt. Palomar. In that area there was a cult which organized sunset or sunrise meetings for the observation of UFO's, the details of which were truly astounding. The Palomar astronomers were accused by members of the cult of keeping their secrets on the UFO's seen and captured (one of which was the 18-foot diameter bowl-shaped Hartmann diaphragm used in testing the 200-inch Hale telescope!). I became acquainted with the role of Mr. Adamski who lived at the foot of Palomar Mt. and who teamed up with an Englishman who was a writer. Together they produced a book, "Flying Saucers Have Landed," that became a best seller. The lore concerning authors of this book who frequently visited Mt. Palomar, was the subject of much conversation among the Palomar and Mt. Wilson service staffs, and revealed much on the reliability or lack thereof in the material presented.

I should correct a statement that has been made that scientists have shied away from UFO reports for fear of ridicule. As a practicing scientist, I want to state categorically that this is nonsense. A scientist's research is self-directed. He knows how limited and cut-up is the time he can devote to research, between his numerous other duties. He selects his area of investigation not because of pressures but because he sees the possibility of making some significant scientific advance. We are living in a period of explosive growth of science, and the scientist has dozens of choices. He selects in much the same manner in which a hiker selects a path over a dangerous mountain slope or through a jungle. At all times he fights against time and he knows that his scientific reputation is at stake. If his judgment was right, he will get results and be praised by his peers. A scientist would consider the discovery of evidence of life on another planet as perhaps the greatest contribution he could make and one that might earn him the Nobel Prize. But this is no reason for him to chase every will-o'-the-wisp. A scientist chooses

his field of inquiry because he believes it holds real promise. If later his choice proves wrong, he will feel very badly and try to sharpen his criteria before he sets out again. Thus, if society finds that most scientists have not been attracted to the UFO problem, the explanation must be that they have not been impressed with the UFO reports. In my own case, after having examined several dozen of them during the past twenty years, I have found nothing that was worthy of further attention. Each scientist must, of course, make this kind of decision for himself. Anyone who is curious or impressed has the privilege to follow them up and is free to solicit the interest of others.

The subject of the UFO reports may be put in perspective by looking at two somewhat analogous cases: (1) the announcement of the discovery of extraterrestrial living organisms in meteorites; and (2) the case of Martian "canals." Most people, even scientists, have little appreciation for the extreme hostility to life of outer space; and most of us, through education or cultural tradition, would like to believe that life on earth is not alone. Every straw in the wind that might point toward the existence of life elsewhere is seized upon and made an object of veneration, if not of a new cult.

In both the detection of organisms in meteorite falls and in establishing that some UFO's may come from outer space, we have the difficulty that <u>our test areas, the earth and its atmosphere, are literally crowded with organisms and gadgets; and that the atmosphere itself exhibits ever-changing meteorological and electrical phenomena</u>. The problem is more difficult than finding a needle in a haystack; it is finding a piece of extra-terrestrial hay in a terrestrial haystack, often on the basis of reports of believers in extra-terrestrial hay. The initially enthusiastic reports of finds of extra-terrestrial organisms in meteorites are now attributed to terrestrial contaminations. The "unpopular" scientist who at the outset discounted this "evidence" as preposterous has been vindicated; but society has suffered "the loss of a dream," and some of its members may bear a grudge

to those who destroyed the dream.

The canals of Mars were reported by Schiaparelli, a well-known Italian scientist of the last century, who made them the basis of major speculation on the presence of intelligent life on Mars. These ideas were taken over by enthusiastic persons with literary interest in the U. S. and further developed. The careful observers with better telescopes who continued to denounce the "canals" as optical elusions were castigated. This controversy brought disrepute to planetary science and weakened its status in universities. To this day the effects have not been overcome and affect even the NASA programs adversely through inadequate academic scientific support. Mariner IV seems to have done what these careful observers of the past half century were unable to do, namely, to destroy in the public mind the myth of the canals of Mars and all that it implied. This indicates, if such were necessary, that even reports by scientists may at times be found to be premature or foolish and that no subject is so well established that continued and more careful scientific investigation is superfluous.

Before leaving the subject of the Martian canals it is instructive to see how the cult was perpetuated in the semi-professional literature for decades. For many years W. H. Pickering, the brother of the famous Harvard astronomer E. C. Pickering, collected amateur observations of Martian canals and published the results in 44 reports in Popular Astronomy. The amateur observers were "rated" by the number of "canals" they had noted. Thus, there was a premium on reporting many canals. Pickering himself compared them in one of these Popular Astronomy reports with the hedges he had seen while flying over the Azores, speculating that the Martian canals were hedges designed to prevent dust and vegetation from blowing from one area to another (the "hedges" were often hundreds of miles long and 25-100 miles wide).

What then, may be regarded as scientific "truth" and a proper standard of finding this truth? How does this affect the scientist's position to the UFO's? I believe that most scientists hold one or two of their senior colleagues in such

high regard that they limit their standard of reference largely to them. In physics, in the 1920's and 30's, Niels Bohr had this distinction in Europe, and later Fermi in the U. S.

To a person seriously proposing that 100 or more of the 10,000 UFO's recorded arrived on earth from outer space, a few questions should be put. One is that of the planets in our solar system (other than earth) only Mars appears to have a remote possibility of harboring life. The very tenuous atmosphere (ground pressure about 1% of the terrestrial atmosphere) and the absence of free oxygen, coupled with the extremely low water-vapor content and the penetration of near-ultraviolet radiation to the Martian surface, combine almost certainly to exclude Mars as a suitable breeding ground for <u>energetic</u> "beings" such as would build and man "space vehicles." If it is assumed instead that the UFO's come from <u>outside</u> the solar system, one finds that the nearest possible location would be planets accompanying stars more than 4-10 light years away. Since it is impossible to exceed the velocity of light and or even approach it with finite energies, one must assume that the space voyages would last decades or centuries. Then it is hard to see how there could have been a sudden increase in a few years; also, how any civilization could afford so many missions per year, all to <u>one</u> distant planet! This is certainly entirely inconceivable here. Further, why intelligent beings would wish to investigate remote deserts (such as in New Mexico) instead of obvious evidence of intelligence on earth, such as large cities. Also, why this remote development would occur just as our own development of aircraft and space vehicles took place in a total life span of the universe of over 10 billion years. Further, why have no UFO's been observed by groups of competent observers working over many years in such countries as England (Members of the British Astronomical Association).

Finally, it has been stated at this meeting that the Robertson Report was unfortunate and was used to suppress evidence. Since it is admitted even by UFO advocates that some 99% are terrestrial and based on faulty interpretation, it must have seemed proper for a responsible group advising the Government to caution against hysteria at the time when our military forces were experimenting with new

equipment, scientists were using new types of balloons and other atmospheric devices, and international tensions were high. Since it is the Department of Defense that has the duty to guard against unwanted aerial invasion, it is logical and proper that they have the responsibility for watching for unexpected aircraft and other aerial devices; and it would seem proper for the Robertson Report to contain a statement that no hostile craft had so far been sighted.

It is reiterated that no greater progress in science can be made than through discovery of a totally new phenomenon. However, only when UFO observations are made that convince a number of competent scientists that something really significant may have occurred, will they drop their active programs and redirect their efforts. The near absence of present scientific participation can only reflect that the reports have been found wanting.

Again, if one proposes that UFO reports merit scientific inquiry, one must also admit that in no other field of inquiry the scientist is so handicapped by an odd and discouraging assemblage of "data." More than 90% of these reports are found to be hoaxes or poor accounts of well-known or trivial events. Under those circumstances an unexplained residue of perhaps 10% is no basis to believe in miracles. It is more reasonable to assume that this residue is so distorted or incomplete as to defy all analysis.

If this were a period in science of exceptional dullness, it might be still possible to arouse interest; but with the incredible progress currently being made in all fields of the natural and biological sciences, few professional scientists will feel called upon to enter the jungle.

Since the Department of Defense has both the obligation and the means to observe foreign spacecraft and similar devices, and since this Department also has access to information on experimental "aircraft," this channel appears to be the only logical one to bring a measure of reliability and sanity into this subject. Until not 100 but <u>one</u> case is established to be of scientific interest, the

entire subject will remain fanciful to most practicing scientists. They may quote Einstein, whose opinion was asked on UFO reports: "I am sure they saw something."

In assessing the UFO reports one must make allowances for the lack of experience of most observers in reporting precisely and objectively on natural phenomena. Thus in the reports, the observations themselves may be buried beneath interpretations that reflect the mental reference frame of the reporters. Much of the present generation has been weaned on science fiction, and the UFO reports reflect not only the images thus acquired but its cavalier disregard of natural law. Earlier generations had different backgrounds and believed in and reported seeing mermaids on rocks, miracles, and more recently, sea serpents.

It is surprisingly difficult to devise adequate scientific surveys of very rare natural phenomena. The experience of the Smithsonian Prairie Meteorite Network, organized through numerous stations equipped with the most modern cameras and supporting electronic equipment, illustrates this point: No meteorites have so far been recovered from the mass of excellent photographic trajectories obtained over a period of about 3 years. Similarly, no adequate data yet exist of ball lightning (a phenomenon known for at least a century) and other atmospheric plasma phenomena. Nevertheless, a special effort could be made in the Department of Defense or the Federal Aviation Agency, largely with existing facilities, to obtain reliable records of any unexpected objects or phenomena that may occur in our atmosphere. This would clear away the present jungle of uncertainty, hopes, disillusionment, and frustration; and would probably lead to new discoveries about our environment.

APPENDIX D: LETTER - J.E. LIPP
TO BRIGADIER GENERAL PUTT
PROJECT "SIGN" NO F-TR-2274-IA APPENDIX "D"

13 December 1948 AL-1009

Brigadier General Putt
United States Air Force
Director of Research and Development
Office, Deputy Chief of Staff, Materiel
Washington 25, D.C.

Dear General Putt:

Please refer to your letter of 18 November 1948 relative to the "flying object" problem and to Mr. Collbohm's reply dated 24 November 1948. In paragraph (b) of the reply, Mr. Collbohm promised (among other things) to send a discussion of the "special design and performance characteristics that are believed to distinguish space ships."

This present letter gives, in very general terms a description of the likelihood of a visit from other worlds as an engineering problem and some points regarding the use of space vehicles as compared with descriptions of the flying objects. Mr. Collbohm will deliver copies to Colonel McCoy at Wright-Patterson Air Base during the RAND briefing there within the next few days.

A good beginning is to discuss some possible places of origin of visiting space ships. Astronomers are largely in agreement that only one member of the Solar system (besides Earth) can support higher forms of life. It is the planet Mars. Even Mars appears quite desolate and inhospitable so that a race would be more occupied with survival than we are on Earth. Reference 1 gives adequate descriptions of conditions on the various planets and satellites. A quotation from Ref. 1 (p.229) can well be included here.

> "Whether intelligent beings exist to appreciate these splendors of the Martian landscape is pure speculation. If we have correctly reconstructed the history of Mars, there is little reason to believe that the life processes may not have followed a course similar to terrestrial evolution. Wtth this assumption, three general possibilities emerge. Intelligent beings may have protected

themselves against the excessively slow loss of atmosphere, oxygen and water, by constructing homes and cities* with the physical conditions scientifically controlled. As a second possibility, evolution may have developed a being who can withstand the rigors of the Martian climate. Or the race may have perished.

"These possibilities have been sufficiently expanded in the pseudo-scientific literature to make further amplification superfluous. However, there may exist some interesting restrictions to the anatomy and physiology of a Martian. Rarity of the atmosphere, for example, may require a completely altered respiratory system for warm-blooded creatures. If the atmospheric pressure is much below the vapor pressure of water at the body temperature of the individual, the process of breathing with our type of lungs becomes impossible. On Mars the critical pressure for a body temperature of 98.6°F. occurs when a column of the atmosphere contains one sixth the mass of a similar column on the Earth. For a body temperature of 77°F. the critical mass ratio is reduced to about one twelfth, and at 60°F. to about one twenty-fourth. These critical values are of the same order as the values estimated for the Martian atmosphere. Accordingly the anatomy and physiology of a Martian may be radically different from ours - but this is all conjecture.

"We do not know the origin of life, even on Earth. We are unable to observe any signs of intelligent life on Mars. The reader may form his own opinion. If he believes that the life force is universal and that intelligent beings may have once developed on Mars, he has only to imagine that they persisted for countless generations in a rare atmosphere which is nearly devoid of oxygen and water, and on a planet where the nights are much colder than our arctic winters. The existence of intelligent life on Mars is not impossible but it is completely unproven."

It is not too unreasonable to go a step further and consider Venus as a possible home for intelligent life. The atmosphere, to be sure, apparently consists mostly of carbon dioxide with deep clouds of formaldehyde droplets, and there seems to be little or no water. Yet living organisms might develop in chemical environments that are strange to us: the vegetable kingdom, for example, operates on a fundamentally different energy cycle from Man. Bodies might be constructed and operated with different chamicals and other physical principles than any

of the creatures we know. One thing is evident: fishes, insects, and mammals all manufacture within their own bodies complex chemical compounds that do not exist as minerals. To this extent, life is self-sufficient and might well adapt itself to any environment within certain limits of temperature (and size of creature).

Venus has two handicaps relative to Mars. Her mass, and gravity, are nearly as large as for the Earth (Mars is smaller) and her cloudy atmosphere would discourage astronomy, hence space travel. The remaining Solar planets are such poor prospects that they can be ignored.

In the next few paragraphs, we shall speak of Mars. It should be understood that most of the remarks apply equally well to Venus.

Various people have suggested that an advanced race may have been visiting Earth from Mars or Venus at intervals from decades to eons. Reports of objects in the sky seem to have been handed down through the generations. If this were true, a race of such knowledge and power would have established some form of direct contact. They could see that Earth's inhabitants would be helpless to do interplanetary harm. If afraid of carrying diseases home, they would at least try to communicate. It is hard to believe that any technically accomplished race would come here, flaunt its ability in mysterious ways and then simply go away. To this writer, long-time practice of space travel implies advanced engineering and science, weapons and ways of thinking. It is not plausible (as many fiction writers do) to mix space ships with broadswords. Furthermore, a race which had enough initiative to explore among the planets would hardly be too timid to follow through when the job was accomplished.

One other hypothesis needs to be discussed. It is that the Martians have kept a long-term routine watch on Earth and have been alarmed by the sight of our A-bomb shots as evidence that we are warlike and on the threshold of space travel. (Venus is eliminated here because her cloudy atmosphere would make such a survey impractical). The first flying objects were sighted in the Spring of 1947, after a total 5 atomic bomb explosions, i.e., Alamogordo, Hiroshima, Nagasaki, Crossroads A and Crossroads B. Of these, the first two were in positions to be seen from Mars, the third was very doubtful (at the edge of Earth's disc in daylight) and the last two were on the wrong side of Earth. It is likely that Martian astronomers with their thin atmosphere, could build telescopes big enough to see A-bomb explosions on Earth, even though we were 165 and 153 million miles away, respectively, on the Alamogordo and Hiroshima dates. The weakest point in the hypothesis is that a continual, defensive watch of Earth for long periods of time (perhaps thousands of years) would be dull sport, and no race that resembled Man would undertake it. We haven't even considered the idea for Venus or Mars, for example.

The chance that Martians, under such widely divergent conditions, would have a civilization resembling our own is extremely remote. It is particularly unlikely that their civilization would be within a half century of our own state of advancement. Yet in the last 50 years we have just started to use aircraft and in the next 50 years we will almost certainly start exploring space.

Thus it appears that space travel from another point within the Solar system is possible but very unlikely. Odds are at least a thousand-to-one against it.

This leaves the totality of planets of other stars in the Galaxy as possible sources. Many modern astronomers believe that planets are fairly normal and logical affairs in the life history of a star (rather than cataclysmic oddities) so that many planets can be expected to exist in space.

To narrow the field a little, some loose specifications can be written for the star about which the home base planet would revolve. Let us say that the star should bear a family resemblance to the Sun, which is a member of the so-called "main-sequence" of stars, i.e., we eliminate white dwarfs, red giants and supergiants. For a description of these types, see reference 2, chapter 5. There is no specific reason for making this assumption except to simplify discussion: we are still considering the majority of stars.

Next, true variable stars can be eliminated, since conditions on a planet attached to a variable star would fluctuate too wildly to permit life. The number of stars deleted here is negligibly small. Reference 3, pages 76 and 85 indicate that the most common types are too bright to be in nearby space unnoticed. Lastly, we shall omit binary or multiple stars, since the conditions for stable planet orbits are obscure in such cases. About a third of the stars are eliminated by this restriction.

As our best known sample of space we can take a volume with the Sun at the center and a radius of 16 light years. A compilation of the 47 known stars, including the Sun, within this volume is given in reference 4, pages 52 to 57. Eliminating according to the above discussion: Three are white dwarfs, eight binaries account for 16 stars and two trinaries account for 6 more. The remainder, 22 stars, can be considered as eligible for habitable planets.

Assuming the above volume to be typical, the contents of any other reasonable volume can be found by varying the number of stars proportionately with the volume, or with the radius cubed, $S_e = 22 \times \left(\frac{r}{16}\right)^3$, where

S_e is number of eligible stars and r is the radius of the volume in light years. (This formula should only be used for radii greater than 16 light years. For smaller samples we call for a recount. For example, only one known eligible star other than the Sun lies within eight light years).

Having an estimate of the number of useable stars, it is now necessary to make a guess as to the number of habitable planets. We have only one observed sample, the Solar system, and the guess must be made with low confidence, since intelligent life may not be randomly distributed at all.

The Sun has nine planets, arranged in a fairly regular progression of orbits (see reference 1, Appendix I) that lends credence to theories that many stars have planets. Of the nine planets, (one, the Earth) is completely suitable for life. Two more (in adjacent orbits) are near misses: Mars has extremely rigorous living conditions and Venus has an unsuitable atmosphere. Viewed very broadly indeed, this could mean that each star would have a series of planets so spaced that one, or possibly two, would have correct temperatures, correct moisture content and atmosphere to support civilized life. Let us assume that there is, on the average, one habitable planet per eligible star.

There is no line of reasoning or evidence which can indicate whether life will actually develop on a planet where the conditions are suitable. Here again, the Earth may be unique rather than a random sample. This writer can only inject some personal intuition into the discussion with the view that life is not unique on Earth, or even the random result of a low probability, but is practically inevitable in the right conditions. This is to say, the number of inhabited planets is equal to those that are suitable!

One more item needs to be considered. Knowing nothing at all about other races, we must assume that Man is average as to technical advancement, environmental difficulties, etc. That is, one half of the other planets are behind us and have no space travel and the other half are ahead and have various levels of space travel. We can thus imagine that in our sample volume there are 11 races of beings who have begun space explorations. The formula on page 3 above now becomes

$$R = 11 \times \left(\frac{r}{16} \right)^3$$

where R is the number of races exploring space in a spherical volume of radius $r > 16$ light years.

Arguments like those applied to Martians on page 2 need not apply to races from other star systems. Instead of being a first port-of-call, Earth would possibly be reached only after many centuries of development

and exploration with space ships, so that a vis ing race would be expected to be far in advance of Man.

To summarize the discussion thus far: th nance of space travelers existing at planets attached to neighboring st s is very much greater than the chance of space-traveling Martians. he one can be viewed almost as a certainty (if the assumptions are accepted), whereas the other is very slight indeed.

In order to estimate the relative chances that visitors from Mars or star X could come to the Earth and act like "flying objects", some discussion of characteristics of space ships is necessary.

To handle the simple case first, a trip from Mars to Earth should be feasible using a rocket-powered vehicle. Once here, the rocket would probably use more fuel in slowing down for a landing than it did in initial takeoff, due to Earth's higher gravitational force.

A rough estimate of one way performance can be found by adding so-called "escape velocity" of Mars to that of the Earth plus the total energy change (kinetic and potential) used in changing from one planetary orbit to the other. These are 3.1, 7.0, and 10.7 miles per second, respectively, giving a total required performance of 20.8 miles per second for a one-way flight. Barring a suicide mission, the vehicle would have to land and replenish or else carry a 100% reserve for the trip home.

Let us assume the Martians have developed a nuclear, hydrogen-propelled vehicle (the most efficient basic arrangement that has been conceived here on Earth) which uses half its stages to get here and the remaining stages to return to Mars, thus completing a round trip without refueling, but slowing down enough in our atmosphere to be easily visible (i.e., practically making a landing). Since it is nuclear-powered, gas temperatures will be limited to the maximum operating temperatures that materials can withstand (heat must transfer from the pile to the gas. so cooling can't be used in the pile). The highest melting point compound of uranium which we can find is uranium carbide. It has a melting point of 4560°R. Assume the Martians are capable of realizing a gas temperature of 4500°R (=2500°K), and that they also have alloys which make high motor pressures (3000 psi) economical. Then the specific impulse will be I = 1035 seconds and the exhaust velocity will be c = 33,400 ft/sec (reference 5). Calculation shows that using a single stage for each leg of the journey would require a fuel/gross weight ratio of 0.96 (for each stage) too high to be practical. Using two stages each way (four altogether) brings the required fuel ratio down to 0.81, a value that can be realized.

If, by the development of strong alloys, the basic weight could be kept to 10% of the total wieght for each stage, a residue of 9% could be used for payload. A four-stage vehicle would then have a gross weight $\left(\frac{100}{9}\right)^4 = 15,000$ times as great as the payload; thus, if the payload were 2,000 pounds, the gross weight would be 30 million pounds at initial take-off (Earth pounds).

Of course, if we allow the Martians to refuel, the vehicle could have only two stages* and the gross weight would be only $\left(\frac{100}{9}\right)^2 = 123$ times the payload, i.e., 250,000 pounds. This would require bringing electrolytic and refrigerating equipment and sitting at the South Pole long enough to extract fuel for the journey home, since they have not asked us for supplies. Our oceans (electrolysis to make H_2) would be obvious to Martian telescopes and they might conceivably follow such a plan, particularly if they came here without foreknowledge that Earth has a civilization.

Requirements for a trip from a planet attached to some star other than the Sun can be calculated in a similar manner. Here the e ergy (or velocity) required has more parts: (a) escape from the planet, (b) escape from the star, (c) enough velocity to traverse a few light years of space in reasonable time, (d) deceleration toward the Sun, (e) deceleration toward the Earth. The nearest "eligible" star is an object called Wolf 359 (see reference 4, p. 52), at a distance of 8.0 light years. It is small, having an absolute magnitude of 16.6 and is typical of "red dwarfs" which make up more than half of the eligible populations. By comparison with similar stars of known mass, this star is estimated to have a mass roughly 0.03 as great as the sun. Since the star has a low luminosity (being much cooler and smaller than the Sun) a habitable planet would need to be in a small orbit for warmth.

Of the changes of energy required as listed in the preceding paragraph, item (c), velocity to traverse intervening space, is so large as to make the others completely negligible. If the visitors were long-lived and could "hibernate" for 80 years both coming and going, then 1/10 the speed of light would be required, i.e., the enormous velocity of 18,000 miles per second. This is completely beyond the reach of any predicted level of rocket propulsion.

---

* Actually three stages. On the trip to Earth, the first stage would be filled with fuel, the second stage would contain partial fuel, the third would be empty. The first stage would be thrown away during flight. On the trip back to Mars, the second and third stages would be filled with fuel. The gross weight of the initial vehicle would be of the order of magnitude of a two-stage rocket.

If a race were far enough advanced to make really efficient use of nuclear energy, then a large part of the mass of the nuclear material might be converted into jet energy. We have no idea how to do this, in fact reference 6 indicates that the materials required to withstand the temperatures, etc., may be fundamentally unattainable. Let us start from a jet-propellant-to-gross-weight ratio of 0.75. If the total amount of expended material (nuclear plus propellant) can be 0.85 of the gross weight, then the nuclear material expended can be 0.10 of the gross. Using an efficiency of 0.5 for converting nuclear energy to jet energy and neglecting relativistic mass corrections, then a rocket velocity of half the velocity of light could be attained . This would mean a transit time of 16 years each way from the star Wolf 359, or longer times from other eligible stars. To try to go much faster would mean spending much energy on relativistic change in mass and therefore operating at lowered efficiency.

To summarize this section of the discussion, it can be said that a trip from Mars is a logical engineering advance over our own present technical status, but that a trip from another star system requires improvements of propulsion that we have not yet conceived.

Combining the efforts of all the science-fiction writers, we could conjure up a large number of hypothetical methods of transportation like gravity shields, space overdrives, teleports, simulators, energy beams and so on. Conceivably, among the myriads of stellar systems in the Galaxy, one or more races have discovered methods of travel that would be fantastic by our standards. Yet the larger the volume of space that must be included in order to strengthen this possibility, the lower will be the chance that the race involved would ever find the earth. The Galaxy has a diameter of roughly 100,000 light years and a total mass about two hundred billion times that of the Sun (reference 4). Other galaxies have been photographed and estimated in numbers of several hundred million (reference 2, p.4) at distances up to billions of light years (reference 7, p. 158). The number of stars in the known universe is enormous, yet so are the distances involved. A super-race (unless they occur frequently) would not be likely to stumble upon Planet III of Sol, a fifth-magnitude star in the rarefied outskirts of the Galaxy.

A description of the probable operating characteristics of space ships must be based on the assumption that they will be rockets, since this is the only form of propulsion that we know will function in outer space. Below are listed a few of the significant factors of rocketry in relation to the "flying objects".

(a) Maneuverability. A special-purpose rocket can be made as maneuverable as we like, with very high accelerations either along or normal to the flight path. However, a high-performance space ship will certainly be large and unwieldy and could hardly be designed to maneuver frivolously around in the Earth's atmosphere. The only economical maneuver would be to come down

and go up more or less vertically.

(b) Fuel reserves. It is hard to see how a single rocket ship could carry enough extra fuel to make repeated descents into the Earth's atmosphere. The large number of flying objects reported in quick succession could only mean a large number of visiting craft.

Two possibilities thus are presented. First,a number of space ships could have come as a group. This would only be done if full-dress contact were to be established. Second, numerous small craft might descend from a mother ship which coasts around the Earth in a satellite orbit. But this could mean that the smaller craft would have to be rockets of satellite performance, and to contain them the mother ship would have to be truly enormous.

(c) Appearance. A vertically descending rocket might well appear as a luminous disk to a person directly below. Observers at a distance, however, would surely identify the rocket for what it really is. There would probably be more reports of oblique views than of end-on views. Of course, the shape need not be typical of our rockets; yet the exhaust should be easy to see.

One or two additional general remarks amy be relevant to space ships as "flying objects". The distribution of flying objects is peculiar, to say the least. As far as this writer knows, all incidents have occurred within the United States, whereas visiting spacemen could be expected to scatter their visits more or less uniformly over the globe. The small area covered indicates strongly that the flying objects are of Earthly origin, whether physical or psychological.

The lack of purpose apparent in the various episodes is also puzzling. Only one motive can be assigned; that the space men are "feeling out" our defenses without wanting to be belligerent. If so, they must have been satisfied long ago that we can't catch them. It seems fruitless for them to keep repeating the same experiment.

Conclusions:

Although visits from outer space are believed to be possible, they are believed to be very improbable. In particular, the actions attributed to the "flying objects" reported during 1947 and 1948 seem inconsistent with the requirements for space travel.

Very truly yours,

J. E. Lipp
Missiles Division

JEL:sp

<u>References</u> *(Included in original letter)*

1. "Earth, Moon and Planets", by F. L. Whipple, Harvard Books on Astronomy, Blakiston, 1941.

2. "Atoms, Stars and Nebulae", by Goldberg and Aller; Harvard Books on Astronomy, Blakiston, 1943.

3. "The Story of VariableStars", by Campbell and Jacchia, Harvard Books on Astronomy, Blakiston, 1945.

4. "The Milky Way", by Bok and Bok, Harvard Books on Astronomy, Blakiston, 1941.

5. Calculated Properties of Hydrogen Propellant at High Temperatures. Data provided to RAND by Dr. Altman, then at JPL. Unpublished.

6. "The Use of Atomic Power for Rockets", by R. Serber, Appendix IV Second Quarterly Report, RA-15004, Douglas Aircraft Co., Inc., Project RAND.

7. "Galaxies", by Shapley, Harlow; Harvard Books on Astronomy, Blakiston, 1943.

S-11750

APPENDIX E: REPORT ON NUMERICAL EXPERIMENT ON THE POSSIBLE EXISTENCE OF AN "ANTI-EARTH," BY DR. R. L. DUNCOMBE, U.S. NAVAL OBSERVATORY

To experimentally determine the dynamical effects of a planet located on the other side of the Sun from the Earth, an extra body was introduced at this position in the initial conditions for a simultaneous numerical integration of the equations of motions for the major planets of the solar system.

The numerical integration used was the Stumpf-Schubart program, described in Publications of the Astronomischen Rechen-Institut, Heidelberg, No. 18 (1966). The calculations were performed on an IBM 360/40 computer at the U. S. Naval Observatory.

The initial coordinates and velocities were derived from those given in the above reference by integrating the system to the desired epoch. All the planets from Venus to Pluto were included; the mass of Mercury was included with that of the Sun. On runs in which the anti-Earth planet, Clarion, was included, its initial coordinate and velocity vectors were taken to be the negative of those for the Earth-Moon barycenter at epoch.

The initial epoch was J.D. 244 0000.5 and the integration, using a 2 day step length, was done backward to J.D. 240 0000.5, a period of approximately 112 years. From the integrated coordinates an ephemeris was generated at a 40 day interval.

Four integrations were made. The first was the solar system alone, for use as a comparison standard. The other three included Clarion with three different mass values: Earth + Moon, Moon, and zero. These three integrations were then compared to the solar system standard integration and the differences for all the planets were expressed in ecliptic longitude, latitude, and radius vector. In addition, the separation of Clarion from a straight line through the perturbed Earth-Moon barycenter and Sun was computed in longitude, latitude, and radius vector.

Since the principal perturbations occur in longitude, the following discussion of the three cases is confined to a description of the amplitude of the differences in this coordinate.

Case 1. Mass of Clarion equals Earth + Moon mass.

Separation of Clarion from the center of the Sun exceeded the mean solar radius of 960" after about 10,000 days and reached an amplitude of 10,000" in 112 years. Perturbations of Venus exceeded 1" after 80 days, while perturbations of the Earth and Mars exceeded 1" after 100 days. At the end of 112 years the perturbations induced by Clarion in the motions of Venus, Earth, and Mars reached 1200", 3800", and 1660" respectively.

Case 2. Mass of Clarion equals mass of Moon.

Separation of Clarion from the center of the Sun exceeded the mean solar radius after 17,600 days and in 112 years had reached 3470". Perturbations of the Earth exceeded 1" after 5120 days and reached 26" in 112 years. Perturbations of Venus and Mars exceeded 1" after 2160 days and 2800 days respectively, and reached 15" and 20" respectively in 112 years.

Case 3. Clarion assumed to have zero mass.

As expected there was no effect on the motions of the other planets, but the separation of Clarion from the Sun was very nearly the same amplitude as for Case 2.

Conclusions:

The separation of Clarion from the line joining the Earth and the Sun shows a variation with increasing amplitude in time, the effect being most pronounced for the largest assumed mass. During the 112 years covered by the integration the separation becomes large enough in all cases that Clarion should have been directly observed, particularly at times of morning or evening twilight and during total solar eclipses. The most obvious effect of the presence of Clarion, however, is its influence on the positions of the other planets. During the past 150 years precise observations by means of meridian circles have been made of the motions of the principal planets of the solar system. Differences introduced, by the presence of an anti-Earth (Clarion) of non-negligible mass, in the motions of Venus, Earth, and Mars could not have remained undetected in this period.

APPENDIX F: FAA NOTICE N7230.29

NOTICE

FEDERAL AVIATION AGENCY
Washington, D.C.

N 7230. 29

4/4/67

Cancellation
Date: 12/31/67

SUBJ: REPORTING OF UNIDENTIFIED FLYING OBJECTS (RIS: AT 7230-96)

1. PURPOSE. This notice establishes procedures for reporting of unidentified flying objects (UFO's) by air traffic control specialists.

2. EFFECTIVE DATE. April 20, 1967.

3. REFERENCES. Aeronautical Communications and Pilot Services Handbook 7300.7.

4. BACKGROUND. The University of Colorado is conducting a study project on UFO's. One of their problems is to develop detailed and credible data. Since air traffic control specialists are skilled observers and in many facilities have access to radar, their cooperation is invaluable to the project success.

5. PROCEDURES. All reports submitted for this project are on a voluntary basis, but it should be noted that reports will be held in strict confidence and no details of sightings or names of persons will be released to news media. Telephone reports of radar UFO sightings shall not include names of radar sites from which the data was derived. This is to preclude release of classified information on joint-use radar.

   a. Initial reports on UFO sightings should be transmitted immediately on the FTS system to the University of Colorado by dialing 8-303-447-1000 and requesting phone number 443-6762. When the switchboard operator at the University of Colorado answers, advise that the Federal Aviation Agency is calling with a UFO report and the party designated to accept the call will be connected.

   b. Report should be brief and include such information as:

      (1) Time, place and duration of sighting.

Distribution: FAT-1, 2, 3, 5, 6 (1-5) WRM/AT-3

(2) Method of observation (radar, visual or both). Do not include name of radar site.

(3) Number of objects seen.

(4) Size, distance and motion of object.

(5) Name of person calling and facility of employment.

c. After initial reports of sightings, a later fallow up by Universtiy of Colorado and collaborating scientists at other universities will take place in the form of interviews. Interviews will be conducted only on those sightings that hold special interest for UFO research and will be held at the convenience of the personnel. If the interview concerns a UFO sighting derived from joint-use radar, security clearances at the secret level must be confirmed for the interview group. A listing of those persons cleared will be provided to the air route traffic control centers through Compliance and Security channels.

d. Sighting information received from outside sources shall be handled as specified in Handbook 7300.7, paragraph 463.

APPROVED APRIL 4, 1967

APPENDIX G: U. S. WEATHER BUREAU OPERATIONS MANUAL LETTER 67-16

	WEATHER BUREAU SILVER SPRING, MARYLAND 20910	Operations Manual Letter 67-16

Date of Issue: November 1, 1967	Effective Date: November 1, 1967
In Reply Refer To: W1421	File With: B-99

Subject: Reporting of Unidentified Flying Objects

The University of Colorado, under sponsorship of the U.S. Air Force, is conducting a study of UFO's. Since "ESSA scientists and personnel are among the most skilled and careful observers to be found," the University has asked our cooperation.

All reports submitted for this project are on a voluntary basis and will be held in strict confidence by the University of Colorado.

Weather Bureau observers at stations in the 48 contiguous United States are requested to report any UFO sightings to the University of Colorado by FTS system, telephone 303-447-1000 and request number 443-6762. When the switchboard operator at the University of Colorado answers, advise that the Weather Bureau is calling with a UFO report and the party designated to accept the call will be connected.

Include in the report such information as:

(1) Time, place and duration of sighting
(2) Number of objects seen
(3) Size, distance and motion if known
(4) Your name and station

The University may arrange an interview with, and at the convenience of, the person making the report if the sighting holds special interest for UFO research.

Your cooperation in this important project is appreciated.

This OML is intended for information only at stations in Alaska and in the Pacific since they are not included in this program.

Karl R. Johannessen

Karl R. Johannessen
Associate Director
Meteorological Operations

APPENDIX H: U. S. DEPT. OF AGRICULTURE FOREST SERVICE, ROCKY MTN. REGION, MEMORANDUM TO FOREST SUPERVISORS

TO: Forest Supervisors File No. 1740
5100

FROM: D. S. Nordwall, Regional Forester, By John B. Smith Date: November 24, 1967

SUBJECT: Memorandums of Understanding
Fire Control

Dr. Edward Condon, Department of Physics, University of Colorado, Boulder has requested Region 2 of the Forest Service to cooperate with the University on its UFO (Unidentified Flying Objects) Study. Although the study terminates June 30, 1968, they are anxious to provide a procedure for getting reports from Forest Service observers.

From their standpoint, this is not for the purpose of getting more data, but to get better data. Forest Service people, because of experience, background, and training, should be able to provide more accurate reports--if they observe a UFO. Such reports would become part of a scientific study, and involvements with reporters or news sources should be avoided. The University has also requested reports from FAA and the Weather Bureau.

Standard procedure for Ranger Districts and National Forests to use to report a UFO follows:

A. Report information should include:

1. Time, place, and duration of sighting.

2. Number of objects seen and description of each.

3. Positive identification of a substantive object.

4. Size, distance, and motion if known.

5. Observer's name and station.

B. Report procedure:

1. Ranger District and Forest personnel should report through the Forest Dispatcher (or Forest Supervisor).

2. Forest Dispatcher should notify the Regional Dispatcher or, if no answer, call persons in order listed in the Emergency Forest Fire Plan.

3. Regional Dispatcher (or alternate) will report to Mr. Robert J. Low, University Project Coordinator, UFO Study. On the FTS system, call 303-447-1000 and ask for 443-2211 to reach Mr. Low.

So far as we know, Forest Service people in Region 2 have not sighted a UFO, but the above establishes procedure, and a report should be made if a UFO is sighted.

John B. Smith

APPENDIX I: INDIVIDUALS WHO PARTICIPATED IN THE EARLY WARNING NETWORK

Alexander, Frank
Anderson, Dr. Kenneth V.
Ansevin, Dr. Krystyna
Armstrong, W. P.
Biller, Dr. Harold
Boltjes, Dr. Ben H.
Brake, Robert V.
Bryan, Kenneth E.
Buckalew, Dr. Mary
Cahn, Dr. Harold A.
Callina, Joseph A.
Cecin, Jose A.
Cerny, Paul C.
Ciarleglio, Frank J.
Clapp, Mrs. Carol
Cleaver, Marshall
Cobb, Mrs. Robert
Conron, Frederick E.
Craig, Clark
Darling, Spenser
Davis, Luckett V.
Dibblee, Grant
Donavan, William D.
Dorris, Ralph M.
Duncan, Robert A.
Earley, George W.
Eldridge, Raymond
Emerson, Col. Robert B.
Epperson, Mrs. Idabel
Faulkner, Richard Louis
Fowler, Raymond E.
Friezo, James V.
Frye, Ronald K.
Funk, Carl F.
Ginnings, Dr. G. K.
Grant, Mrs. Verne
Gregory, Jeanne L.
Haber, Dan
Harder, Dr. James
Heiglig, Robert B.
Henry, Dr. Richard C.
Inderwiesen, F. H.
Johnson, Mrs. Jeanne Booth
Kammer, David
Klingaman, David C.
Lansden, David V.
Larson, Mrs. June
Laufer, Dr. L. Gerald
Lewis, Robert M.
Lillian, Irving
Loftin, Capt. Robert E.
Lohr, Lloyd A.
MacDonald, Cynthia M.
McCown, Lowell E.
McLeod, John F.
Meloney, John
Mood, Douglas A.
Morse, Robert F.
Moss, Richard D.
Murdock, Roy E.

Murphy, Terry
Murphy, William
Murray, Dr. Robert
Olson, Donald L.
Park, Dr. Nelson A.
Peterson, Dr. W. C.
Reichman, Louis
Rice, Dr. Herman
Robie, Carl
Roth, Herbert
Rowe, Dr. William E.
Russell, Betty
Rygwalski, Eugene
Salisgury, Dr. Frank B.
Sanders, Rayford R.
Sayer, Dr. Gordon C.
Scegner, Dr. James
Schneider, Dr. Richard V.
Scott, Thomas J.
Seamands, Robert E.
Seff, Dr. Philip
Sipprell, James
Smith, Eugene P.
Sorenscn, Arthur
Stokesberry, John L.
Strand, Lt. Col. Howard C.
Stringfield, Leonard H.
Stroud, Walter J.
Sutton, Charles M.
Swann, Dr. A. Henry
Tull, Clancy D.
Utke, Dr. Allen R.
Wambaugh, Helen A.
Webb, Walter N.
Williams, Roy P.
Worstell, Paula
Zechman, Richard W.

APPENDIX J: EARLY WARNING REPORT FORM

Date ______________________ Time ______________________ Zone __________

Place ________________________________ Classification __________

Duration ______________________ Direction disappeared __________

Visual observers __________ Radar? ______________________

Objects ______________________ Size ______ ______________________

Shape ______________________ Color ______________________

Distance ______________________ Motion ______________________

Other features ____

Weather ____

Known traffic ____

Observer -- Name ______________________________ Age __________

Address ____

Phone ______________________ Occupation ______________

Reporter -- Name ____

Address ____

Phone ______________________ Occupation ______________

Receiver -- ______________ Date ______________ Time __________

Please fill in all possible blanks with relevant information.

Use the back of this sheet for a running description of the event.

DRS -- 6/6/67 (Rev)

APPENDIX K: FIELD KIT INVENTORY LIST

1. INSTRUMENTS AND MISCELLANEOUS

    a. Camera (diffraction grating, filters, operating instructions if necessary, and film)
    b. Movie Camera
    c. Binoculars
    d. Geiger Counter
    e. Flashlight
    f. Compass
    g. Magnifying Glass
    h. Sample Containers
    i. Tape Recorder (Tapes)
    j. Tape Measure
    k. Plaster Casting Material
    l. Pocket Spectroscope
    m. Geologist's Kit
    n. String
    o. Star Finder
    p. Nautical Almanac
    q. Elevation Indicator
    r. Arc Indicator (Size)
    s. Police Radiomonitor

2. PAPER

    a. Notebook and Address Book (Contacts)
    b. Identification Card
    c. Copy of Contract
    d. Orders
    e. Letter of Authorization
    f. Maps (of specific areas)
    g. Road Atlas
    h. Auto Sun-visor Identification Card
    i. Sighting Report Forms/Interview Forms
    j. Copies of 80-17A, 80-17
    k. Tax Exempt Certificates

3. PERSONAL

    a. Boots
    b. Warm Clothing if necessary
    c. Air Tickets (or others)
    d. Money or Traveler's Checks
    e. Credit Cards
    f. Briefcase

NOTE: Carry essentials on person - airline luggage can be delayed.

APPENDIX L: WEATHER CONDITIONS AND RADAR ECHOES NEAR WASHINGTON, D.C., AND NORFOLK, VA., ON 19-20 AND 26-27 JULY 1952

Loren W. Crow

CERTIFIED
CONSULTING METEOROLOGIST

Phone (303) 722-8665 or 756-3971
2422 South Downing Street
Denver, Colorado 80210

April 1, 1968

The following is a summary of weather conditions surrounding UFO visual sightings and co-incident radar echoes near Washington, D.C. and Norfolk, Virginia on the nights of July 19-20, 1952, and July 26-27, 1952.

SOURCES OF DATA

Radiosonde and wind data from -

Washington, D.C., Norfolk, Virginia, and Richmond, Virginia

Surface weather observations surrounding the times of sightings from -

Washington National Airport
Bolling AFB
Andrews AFB
Norfolk, Virginia
Newport News, Virginia
Langley AFB

GENERAL WEATHER SITUATION

The general weather situation during both nights was "hot and muggy." Maxima temperatures of the previous day, the minima and maxima on the following day were:

	19th max.	20th min.-max.	26th max.	27th min.-max.
Washington	93°	76° 90°	90°	75° 94°
Norfolk	98°	78° 95°	89°	72° 98°

On the night of the 19-20 a large, flat high-pressure area of 1020 millibars was located over the Middle Mississippi Valley and a very minor trough existed off the east coast. There were no fronts in the immediate

area of either Washington or Norfolk. The general flow of air was from west to east.

On the night of the 26-27, both Washington and Norfolk were near the center of a flat high-pressure wedge extending from Texas to several hundred miles east of New York City. A light drift from south to north characterized the air flow outward from the central portion of the wedge. Again, there were no fronts in the immediate area of either station.

THE INCIDENCE OF SCATTERED CLOUDS

It would have been possible for observers on the ground to have seen small clouds at both low and middle heights at various times during each of the two nights. Some cloud cover - mostly scattered clouds - was recorded by nearly all the observing stations where trained observers were on duty. A summary of cloud cover conditions is as follows:

a. <u>At Washington</u> on the night of July 19-20.

At 9:30 P.M. the observer mentioned a few altocumulus at 8,000 feet. These altocumulus were not mentioned in subsequent reports until 0454 A.M. on the morning of the 20th when again in the remarks column a few altocumulus were mentioned. The hourly summary indicates a height of these clouds observed near sunrise at 18,000 feet and movement of the cloud from the northwest. The observer at Bolling AFB, just across the river from Washington National Airport, recorded various quantities of middle cloud estimated at 12,000 and 15,000 feet during the early part of the night before 10:30 P.M. No such clouds were reported between 10:30 P.M. and 3:30 A.M. At 4:30 A.M. the observer on duty at Bolling AFB reported scattered clouds at 14,000 feet and a few cumulus clouds at 5,000 feet. Observers at both Washington National Airport and Bolling AFB reported various amounts of cirrus clouds at 25,000 feet.

No low or middle clouds were being reported during the darker portion of the night. It is not uncommon that observations made by trained observers during brief trips outdoors from a lighted room to view a darkened sky fail to report scattered cloud conditions. Another observer who has remained outside long enough for his eyes to adjust to darkened conditions can often see some scattered clouds. Conditions of cloudiness on this night would let some scattered clouds form and dissipate in a reasonably short period of time in any one portion of the sky.

There may have been a few clouds visible to ground observers in the Washington area although they were not being reported by the official observing stations. Both the 19-20 and 26-27 nights occurred during the darker portion of the month since a full moon in July, 1952, occurred on July 7.

At Norfolk on the night of July 19-20.

The scattered conditions at 4,000 feet and varying quantities of cloud at approximately 12,000 feet would have made it possible for a few scattered clouds to have been seen on an intermittent basis at various times during the night.

b. At Washington the night of July 26-27.

Clear conditions prevailed throughout most of the night but when daylight began to arrive between 4:00 and 5:00 A.M., cloudiness was reported as a few stratocumulus at 2,000 feet and some thin scattered cirrus at 25,000 feet. It would have been possible for some clouds to have been visible in the area during the darker portion of the night if an observer permitted his eyes to adjust to the darkness.

At Norfolk the night of July 26-27.

The cloud conditions in the Norfolk area varied considerably between the Norfolk Municipal Airport and the observations made at Langley AFB several miles north of there. Langley reported clear conditions while broken or overcast cloudiness was being reported near 5,000 feet at the Norfolk Municipal Airport.

There would have been a marginal area of dissipating cloud cover somewhere between Norfolk Municipal Airport and Langley AFB. Thus, multiple observers could have had a wide variety of possible cloud sightings.

TEMPERATURE, MOISTURE AND WIND PROFILES

The conditions of the atmosphere were capable of generating anomolous propagation on weather radar displays on both nights. In Battan's book on RADAR METEOROLOGY, published in 1959, page 21, is found the following:

> "Nocturnal radiation, which occurs on clear nights, especially in the summer when the ground is moist, leads to a temperature inversion at the ground and a sharp decrease in moisture with height. It is found that these conditions frequently produce abnormal propagation, which becomes more pronounced as the temperature and humidity lapse rates become larger. . . . . . These conditions which favor ducts at the ground occur most frequently over large land areas in the summer and can be thought of as situations of 'radiative superrefraction'".

More recent studies of anomolous propagation on radar have been made at Texas A & M. They have further confirmed the appearance of radar echoes during night and early morning hours under clear sky conditions when low level inversions and fluctuating quantities of moisture characterize the surrounding atmosphere.

In Figures 1-4, profiles of temperature and dew point, plus wind direction and velocity, are presented. In most instances the vertical profiles near the ground would have had several degrees variation in and around each of the two stations where the radars were located. Using surface temperatures at the several airports and the actual radar sights, there would have been variations of from 3-5°F. in the first few hundred feet. Relatively small change in the vertical profiles would have occurred during the night at elevations greater than 2,500 feet. Respective percentages of relative humidity are recorded next to the moisture profile. The dashed lines report observations made at 10:00 P.M. The solid lines report values at 10:00 A.M. the following morning. The profiles would have changed gradually during the night-time hours but would have remained somewhere between these two soundings. The greatest variability in the local area would have been in the lowest few hundred feet. Near the surface, indications for 4:00 A.M. were made from surface observations.

Of some importance is the fact that rain showers were reported in the Washington area during late afternoon on the 19th of July. Amounts reported at the three stations in the Washington area ranged from .10 through .13. This would have wet the ground and furnished a variable moisture source in different portions of the surrounding country side.

SUMMARY

It is the author's opinion that hot, humid air prevailed on both nights in both Washington and Norfolk. The general weather would have been considered fair weather by the trained observers at the various airports and they may not have reported all the scattered clouds which actually existed. It would have been considered an "easy shift". Visibilities remained above six miles at all times. The horizontal movement of scattered clouds, plus formation and dissipation of some few low clouds, both could have been seen at various times by ground observers whose eyes were well adjusted to the darkened sky. Anomolous propagation could have been observed on weather radar units during both nights at both locations. The echoes due to anomolous propagation would have had horizontal motion similar to the clouds.

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Certified Consulting
Meteorologist

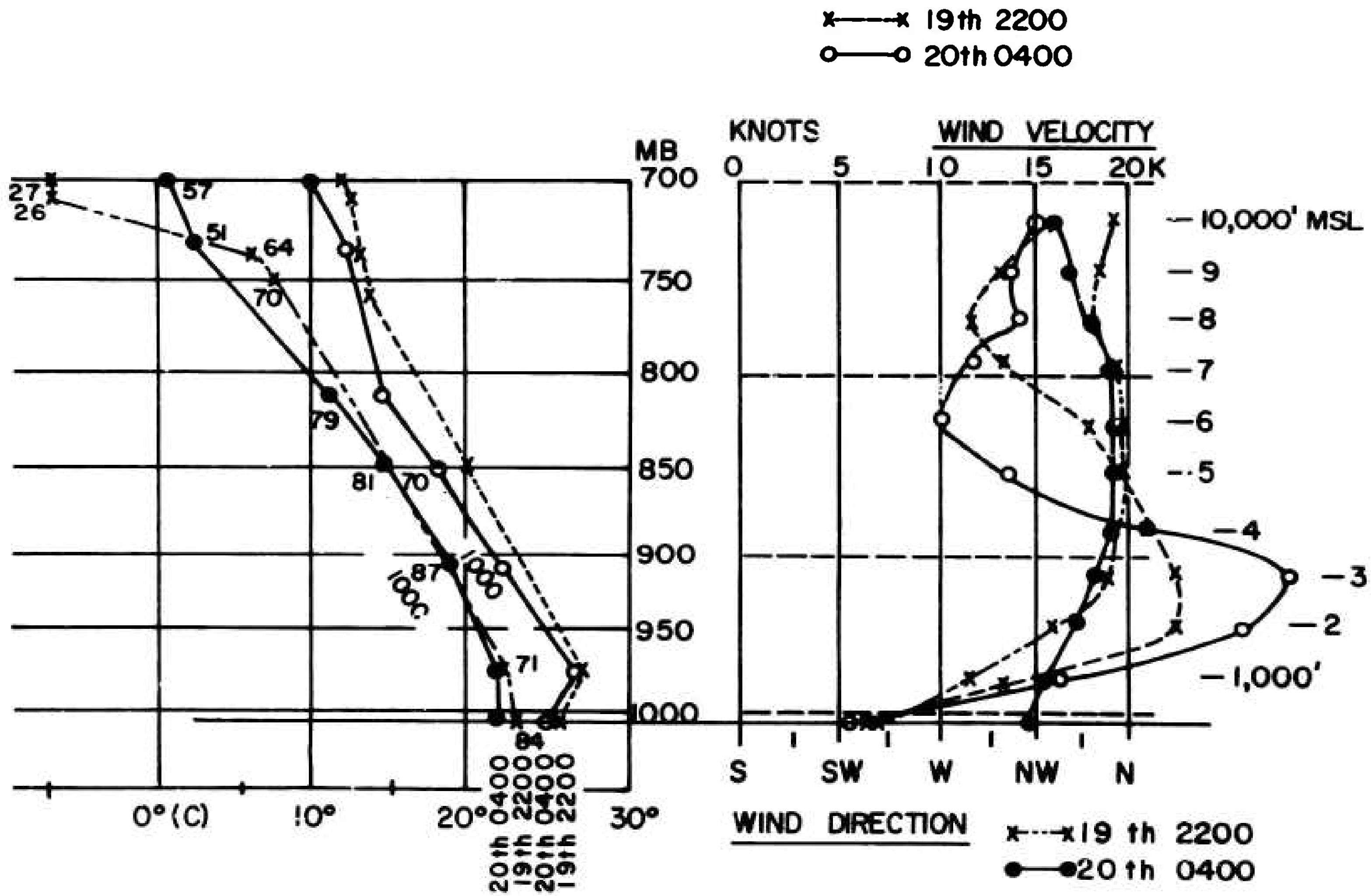

Fig. 1 Profiles of Temperature, Dew Point, Relative Humidity, Wind Direction and Velocity related to UFO sightings during the night of July 19-20, 1952 near Washington, D. C.

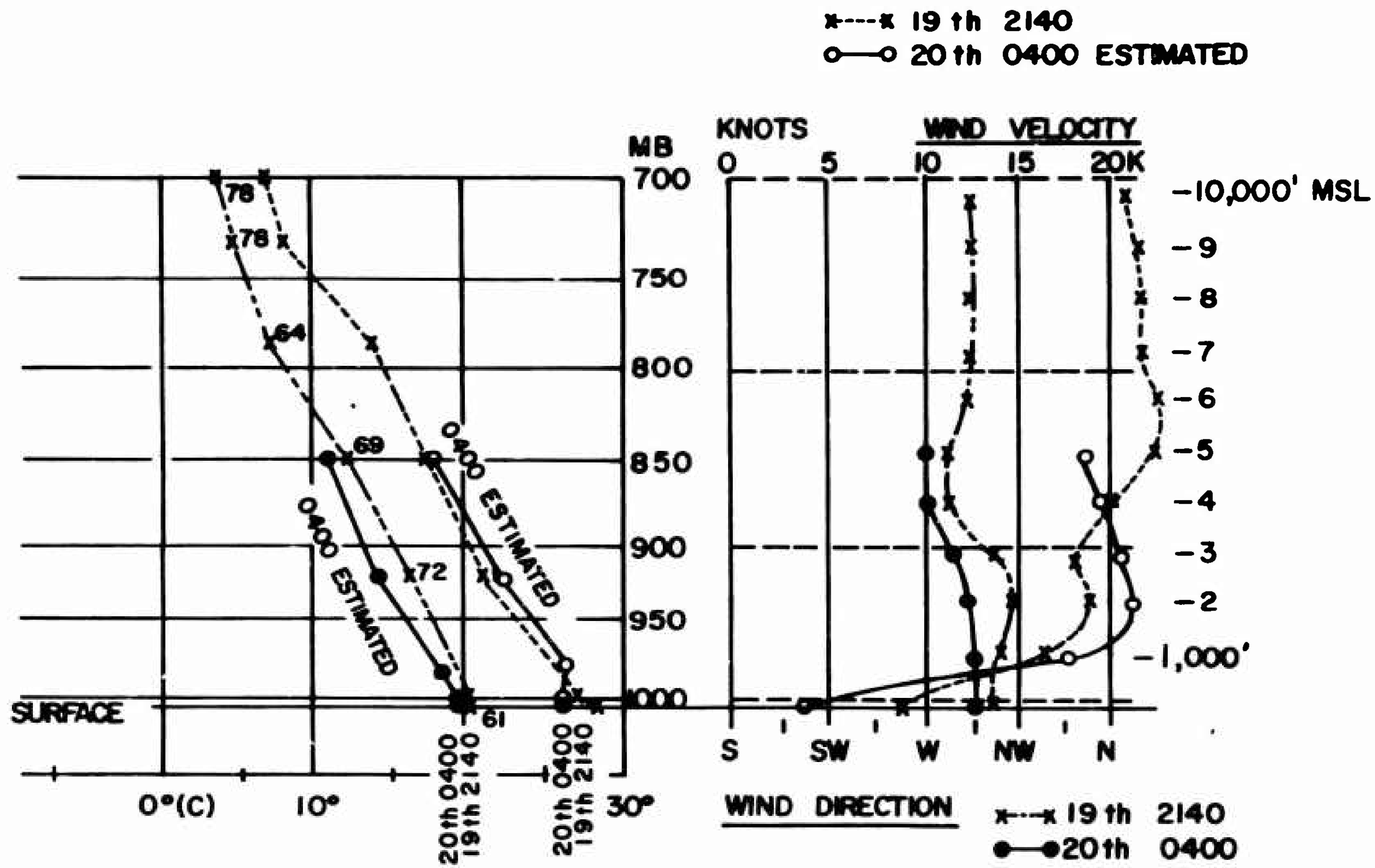

Fig. 2 Profiles of Temperature, Dew Point, Relative Humidity, Wind Direction and Velocity related to UFO sightings during the night of July 19-20, 1952, near Norfolk, Virginia.

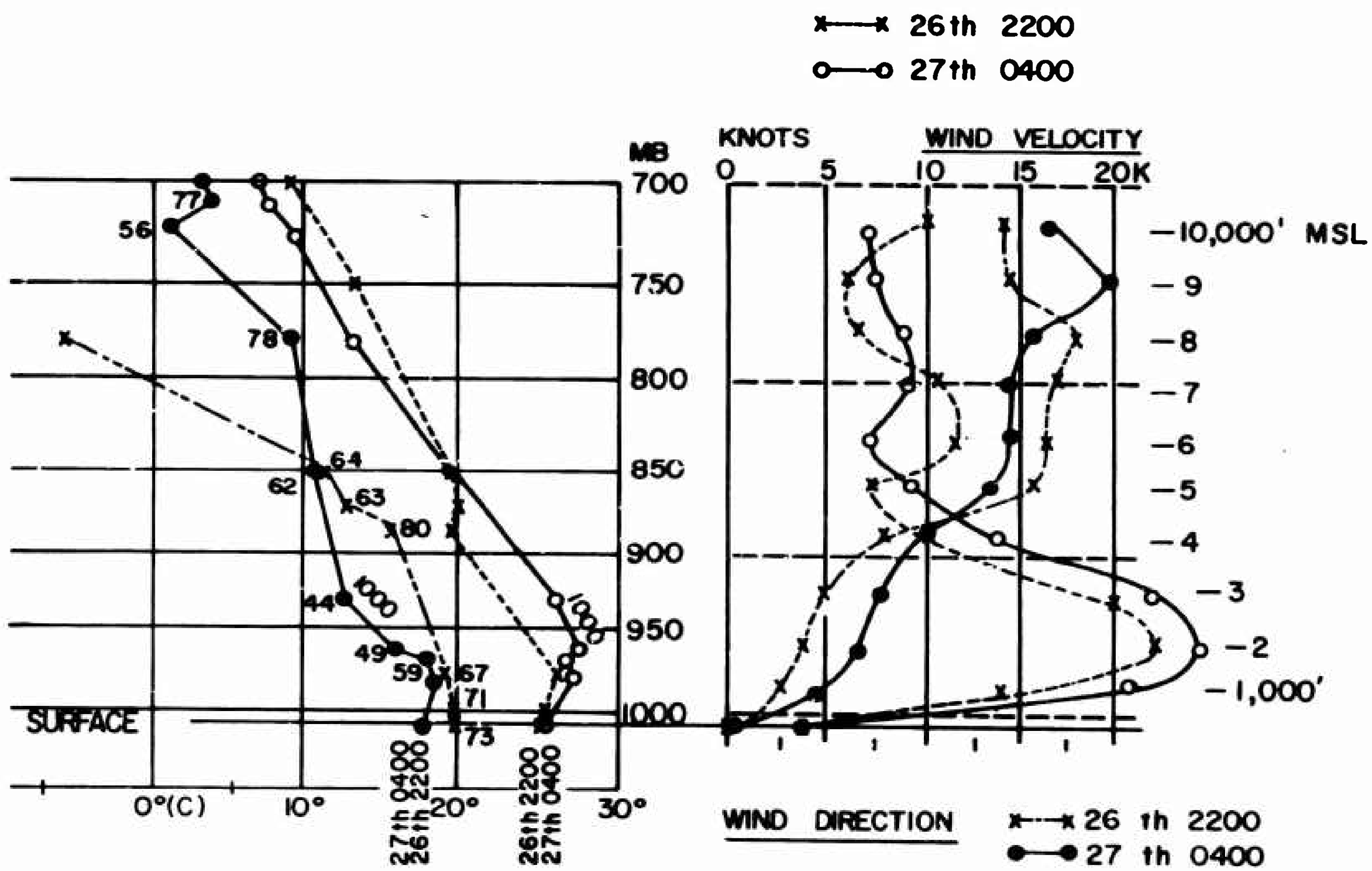

Fig. 3 Profiles of Temperature, Dew Point, Relative Humidity, Wind Direction and Velocity related to UFO sightings during the night of July 26-27, 1952, near Washington, D. C.

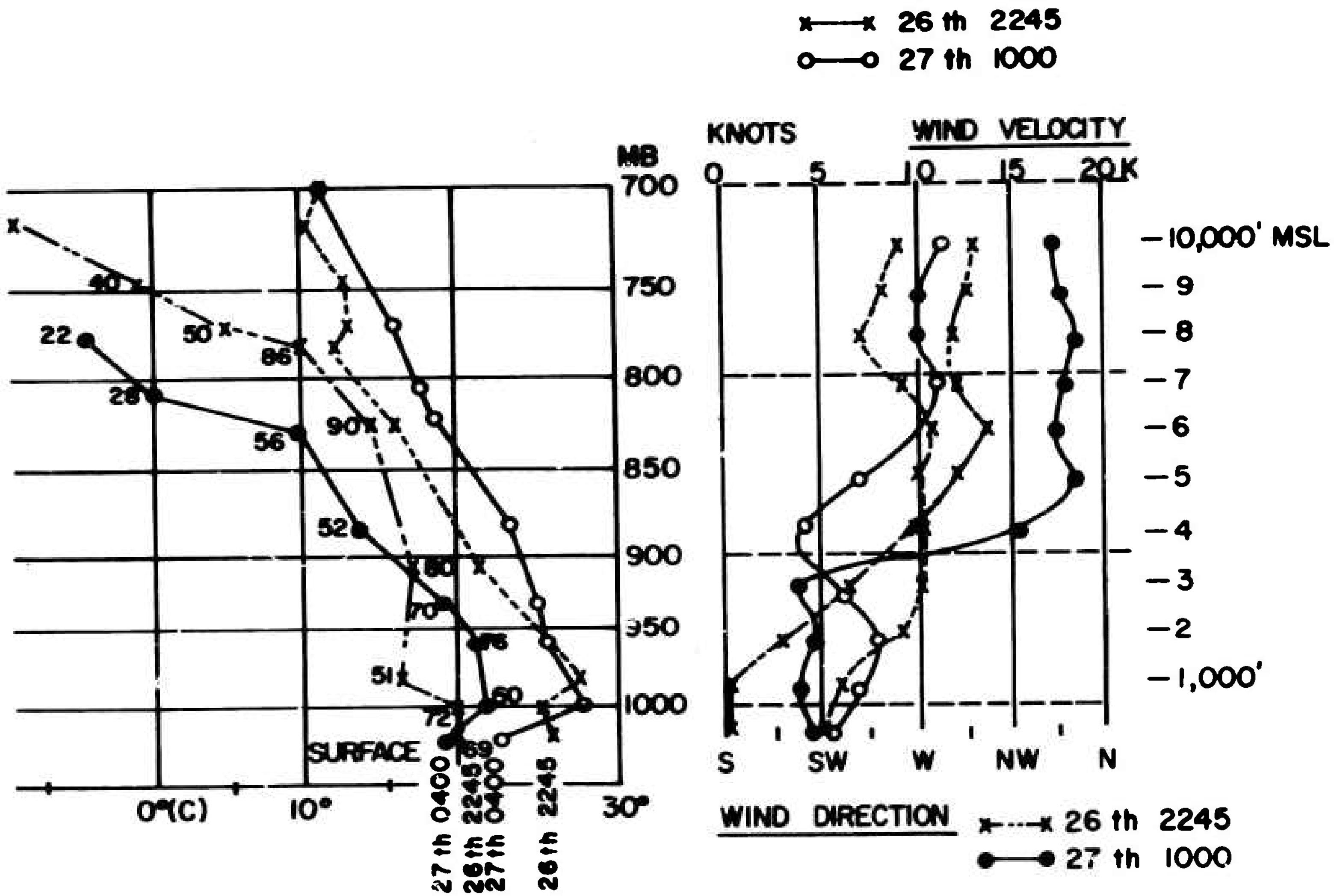

Fig. 4 Profiles of Temperature, Dew Point, Relative Humidity, Wind Direction and Velocity related to UFO sightings during the night of July 26-27, 1952, near Norfolk, Virginia.

APPENDIX M: SOURCES OF COLLEGE SURVEY DATA AND PERSONS INSTRUMENTAL IN OBTAINING DATA

Institutions	Data Resource Persons
Arizona State University	Professor John W. Reich
Bemidji State College	Professor Kathryn Bradfield
Carleton College	Professor William R. Kirtner Professor R. Thomas Rosin
University of California at Davis	Professor Dennis Livingston Professor Paul Moller
University of California at Irvine	Professor Arnold Binder
University of Colorado	Professor Neil G. Fahrion Professor Joshua Gerow Professor Robert Rogers
University of Montana	Mr. Victor Joe Professor John Means
Northwestern University	Professor John I. Kitsuse Mr. Herbert Strentz
University of Utah	Professor Donna M. Gelfand Professor Donald P. Hartman
Wesleyan University	Professor Thornton Page

APPENDIX N: UFO OPINION QUESTIONNAIRE

The following statements all have to do with Unidentified Flying Objects -- often called "U-F-O's." One type of U-F-O is a "flying saucer." The statements are ideas, or opinions, not necessarily facts -- so people differ in the degree to which they believe them to be true or false.

For each of the statements shown below, please indicate the degree to which you feel the statement to be either true or false:

1. Definitely false means that you are fully convinced the statement is false, and you would act without hesitation on this belief. You would question the wisdom of anyone who disagreed with you.

2. Probably false means that you are not sure whether the statement is true or false, but that if you had to act on it, you would regard the statement as more likely false than true. Your opinion might be changed by discussion with another person.

3. Probably true means that you are not sure whether the statement is true or false, but that if you had to act on it, you would regard the statement as more likely true than false. Your opinion might be changed by discussion with another person.

4. Definitely true means that you are fully convinced that the statement is true, and you would act without hesitation on this belief. You would question the wisdom of anyone who disagreed with you.

To indicate your belief, place an X in the appropriate box next to the item. Do not skip any item.

	Definitely False	Probably False	Probably True	Definitely True
1. Some flying saucers have tried to communicate with us.				
2. All UFO reports can be explained either as well understood happenings or as hoaxes.				
3. The Air Force is doing an adequate job of investigation of UFO reports and UFOs generally.				
4. No actual, physical evidence has ever been obtained from a UFO.				
5. A government agency maintains a Top Secret file of UFO reports that are deliberately withheld from the public.				

	Definitely False	Probably False	Probably True	Definitely True
6. No airline pilots have seen UFOs.				
7. Most people would not report seeing a UFO for fear of losing a job.				
8. No authentic photographs have ever been taken of UFOs.				
9. Persons who believe they have communicated with visitors from outer space are mentally ill.				
10. The Air Force has been told to explain all UFO sightings reported to them as natural or man-made happenings or events.				
11. Earth has been visited at least once in its history by beings from another world.				
12. The government should spend more money than it does now to study what UFOs are and where they come from.				
13. Intelligent forms of life cannot exist elsewhere in the universe.				
14. Flying saucers can be explained scientifically without any important new discoveries.				
15. Some UFOs have landed and left marks in the ground.				
16. Most UFOs are due to secret defense projects, either ours or another country's.				
17. UFOs are reported throughout the world.				
18. The government has done a good job of examining UFO reports.				
19. There have never been any UFO sightings in Soviet Russia.				
20. People want to believe that life exists elsewhere than on Earth.				
21. There have been good radar reports of UFOs.				

	Definitely False	Probably False	Probably True	Definitely True
22. There is no government secrecy about UFOs.				
23. People have seen space ships that did not come from this planet.				
24. Some UFO reports have come from astronomers.				
25. Even the most unusual UFO report could be explained by the laws of science if we knew enough science.				
26. People who do <u>not</u> believe in flying saucers must be stupid.				
27. UFO reports have not been taken seriously by any government agency.				
28. Government secrecy about UFOs is an idea made up by the newspapers.				
29. Science has established that there are such things as "Unidentified Flying Objects."				

APPENDIX O: A-B SCALE

This scale is an abridgment of Rotter's I-E Scale (Rotter, 1966), which measures the tendency of the individual to perceive events as contingent on his own behavior or independent of it (i.e., contingent upon forces external to him).

Here are six sets of statements. For each set please tell me which comes closer to being true, in your opinion. There are no right or wrong answers -- just pick one statement in each set that comes closest to how you feel.

A. First --

Without the right breaks one cannot be an effective leader. 1

- or that -

Capable people who fail to become leaders have not taken advantage of their opportunities. 2

B. Next, which comes closest to your opinion -

Becoming a success is a matter of hard work, luck has little or nothing to do with it. 1

- or that -

Getting a good job depends mainly on being in the right place at the right time. 2

C. Which comes closest to your opinion -

Who gets to be the boss often depends on who was lucky enough to be in the right place first. 1

- or that -

Getting people to do the right thing depends upon ability, luck has little or nothing to do with it. 2

D. Which comes closest to your opinion -

As far as world affairs are concerned, most of us are victim of forces we can neither understand nor control. 1

- or that -

By taking an activepart in political and social affairs the people can control world events. 2

A-B SCALE (cont'd)

E. Next,

Most people don't realize the extent to which their lives are controlled by accidental happenings. 1

- or that -

There really is no such thing as "luck." 2

F. Finally,

Many times I feel that I have little influence over things that happen to me. 1

- or that -

It is impossible for me to believe that change or luck plays an important role in my life. 2

INSTRUCTIONS FOR THE A-B SCALE

Each item consists of a pair of statements lettered a or b. For each set, circle the letter which stands for the one which comes closer to being true, in your opinion. There are no right or wrong answers -- just pick one statement in each set that comes closest to how you feel.

a b 1. a) Children get into trouble because their parents punish them too much.
b) The trouble with most children nowadays is that their parents are too easy with them.

a b 2. a) In the long run people get the respect they deserve in this world.
b) Unfortunately, an individual's worth often passes unrecognized no matter how hard he tries.

a b 3. a) Without the right breaks one cannot be an effective leader.
b) Capable people who fail to become leaders have not taken advantage of their opportunities.

a b 4. a) Becoming a success is a matter of hard work, luck has little or nothing to do with it.
b) Getting a good job depends mainly on being in the right place at the right time.

a b 5. a) When I make plans, I am almost certain that I can make them work.
b) It is not always wise to plan too far ahead because many things turn out to be a matter of good or bad fortune anyhow.

a b 6. a) In my case getting what I want has little or nothing to do with luck.
b) Many times we might just as well decide what to do by flipping a coin.

a b 7. a) Who gets to be the boss often depends on who was lucky enough to be in the right place first.
b) Getting people to do the right thing depends upon ability, luck has little or nothing to do with it.

a b 8. a) As far as world affairs are concerned, most of us are the victims of forces we can neither understand, nor control.
b) By taking an active part in political and social affairs the people can control world events.

a b 9. a) Most people don't realize the extent to which their lives are controlled by accidental happenings.
b) There really is no such thing as "luck."

a b 10. a) It is hard to know whether or not a person really likes you.
b) How many friends you have depends upon how nice a person you are.

a b 11. a) A good leader expects people to decide for themselves what they should do.
b) A good leader makes it clear to everybody what their jobs are.

a b 12. a) Many times I feel that I have little influence over the things that happen to me.
b) It is impossible for me to believe that chance or luck plays an important role in my life.

APPENDIX P: CURRENT EVENTS QUESTIONNAIRE

OPINIONS ON CURRENT ISSUES

For each of the statements shown below, please indicated whether you feel the statement is: Definitely True, Probably True, Probably False, or Definitely False.

	Definitely False	Probably False	Probably True	Definitely True
VIET NAM				
1. The U. S. should intensify bombing in Viet Nam.				
2. The U. S. Government should work harder toward peace negotiations in Viet Nam.				
3. More troops should be sent to Viet Nam.				
4. The United States should get out of Viet Nam.				
WAR ON POVERTY				
1. The War on Poverty is necessary to help the poor become self-sufficient.				
2. Too much money is going into government programs to fight poverty.				
3. Poor people should help themselves, instead of relying on the Government for help.				
4. The problems of the poor and uneducated is properly a major concern of the Federal Government.				
KENNEDY ASSASSINATION				
1. Kennedy was shot by a man who was not a part of any conspiracy to kill the President.				
2. Lee Harvey Oswald was a member of, or was used by, a secret group who wanted Kennedy dead.				

	Definitely False	Probably False	Probably True	Definitely True
3. The Warren Report's conclusion that Oswald, alone and without help, assassinated Kennedy is correct.				
4. Either a foreign government or a secret branch of the U. S. Government was responsible for the Kennedy assassination.				
RACE PROBLEMS 1. The Communists have stirred up Negroes and poor whites.				
2. Society, as a whole, is responsible for the current racial tensions.				
3. Racial discrimination is primarily to blame for the summer riots.				
4. The minority groups want to move too fast.				

APPENDIX Q: WEATHER CONDITIONS IN THE AREA BETWEEN DALLAS AND MINERAL WELLS, TEXAS, 19 SEPTEMBER 1957

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June 10, 1968

The following is a summary of weather conditions to determine whether or not the atmosphere was favorable to producing optical mirages and anomalous radar propagation for an area from 50 miles east of Dallas to Mineral Wells, Texas, during the time period from 2:00 A.M. to 3:00 A.M., Central Standard Time, September 19, 1957, for an aircraft flying in that region at elevations between 10,000 to 30,000 feet.

SOURCES OF DATA

Radiosonde and wind data from -

Carswell AFB at Fort Worth

Surface weather observations surrounding the time of UFO sightings from -

Love Field - Dallas, Naval Air Station - Dallas, Carter Field - Fort Worth, Mineral Wells, Tyler, College Station, Perrin AFB, Connolly AFB, Gray AFB.

A special study -

"On the Effects of Atmospheric Refraction on Radar Ground Patterns" by the Department of Oceonography and Meteorology, Texas A & M University, 1963.

National Bureau of Standards Monograph 92 -

"Radio Meteorology", U.S. Department of Commerce, 1966.

GENERAL WEATHER SITUATION

The weather which prevailed in the entire northeast part of Texas during the early morning hours of September 19, 1957, consisted of a stable air mass with clear conditions. Air movement near the surface was from the

southeast at all stations. Table I on the following page presents the actual condition for ceiling, visibility, temperature, dew point, wind direction and velocity at the surface for several surrounding stations. Figure 1 presents the conditions at 2:00 A.M. for these same stations and is representative of conditions that continued beyond 3:00 A.M.

VERTICAL PROFILE OF TEMPERATURE, HUMIDITY AND WIND

The vertical soundings of the atmosphere made about three hours before the UFO sightings and an equal time following gives the vertical profile of atmospheric conditions in the immediate vicinity of the sightings. The radiosondes were released at 11:30 P.M. and 5:30 A.M. respectively from Carswell AFB which is near Fort Worth, Texas.

Probably the most significant portion of the profile is the very rapid decrease in moisture content at a level between 6000 feet and 7000 feet. Temperatures increased with height in this same layer. Beneath this inversion layer the wind direction changed from southerly in the lower part of the atmosphere to a westerly and northerly direction at approximately 6000 feet. Wind velocities increased during the night in the layer between 2000 feet and 5000 feet. Figure 2 presents this pattern for the two different soundings.

EFFECTS OF TEMPERATURE AND HUMIDITY ON REFRACTIVE INDEX

If a radio ray (including radar) is propagated in free space, where there is no atmosphere, the path followed by the ray is a straight line. However, a ray that is propagated through the earth's atmosphere encounters variations in the atmospheric refractive index along its trajectory that caused the ray path to become curved. The total angular refraction of the ray path between two points is commonly called the "bending" of the ray. This "bending" is strongly influenced by rapid changes in refractive index within the atmosphere and such rapid changing in refractive index is caused by rapid changes in the moisture in the air. The <u>typical temperature inversion</u> permits the temperature to increase over a farily short increase in height, while at the same time the amount of moisture decreases rapidly. Experimental work has developed relationships between the moisture content and the refractive index so that data obtained in the vertical sounding of temperature and humidity from a radiosonde can be converted to corresponding values of refractive index. Figure 3 presents the profile of refractive index that directly corresponds with the vertical temperature and humidity profile in Figure 2.

In Figure 3 a <u>critical gradient</u> line is drawn for change in refractive index with height. Later discussion will indicate the importance of this critical gradient.

STANDARD ATMOSPHERE VERSUS ACTUAL ATMOSPHERE

When only a standard atmosphere is considered the change in temperature and humidity with height is quite gradual and there are no sharp changes due to rapid decreases in humidity. Figure 4 gives the typical profiles for a standard atmospheric profile in the top part of the figure. The

Table I. Hourly Weather Conditions Observed Early Morning Hours, September 19, 1957

2:00 A.M.

	Ceiling	Visibility	Temper-ature	Dew Point	Wind Direction & Velocity
Perrin AFB	clear	15 miles	72°F	66°F	SE 9
Mineral Wells	clear	25	72	66	SE 9
Ft. Worth	clear	15+	72	66	SE 10
Naval Air Station	clear	15	75	69	SE 16
Love Field-Dallas	clear	15	74	68	SE 10
Tyler	clear	12	70	67	SE 5
Connally AFB	clear	15	73	67	SSE 3
Gray AFB	clear	15	73	67	SE 4

3:00 A.M.

	Ceiling	Visibility	Temper-ature	Dew Point	Wind Direction & Velocity
Perrin AFB	clear	15	71	66	SE 9
Mineral Wells	clear	25	71	66	SE 10
Ft. Worth	clear	15+	72	67	SE 9
Naval Air Station	clear	15	75	69	SE 14
Love Field-Dallas	clear	15	73	67	SE 10
Tyler	clear	12	70	66	SE 5
Connally AFB	clear	15	72	67	SSE 3
Gray AFB	clear	15	72	64	SSE 6

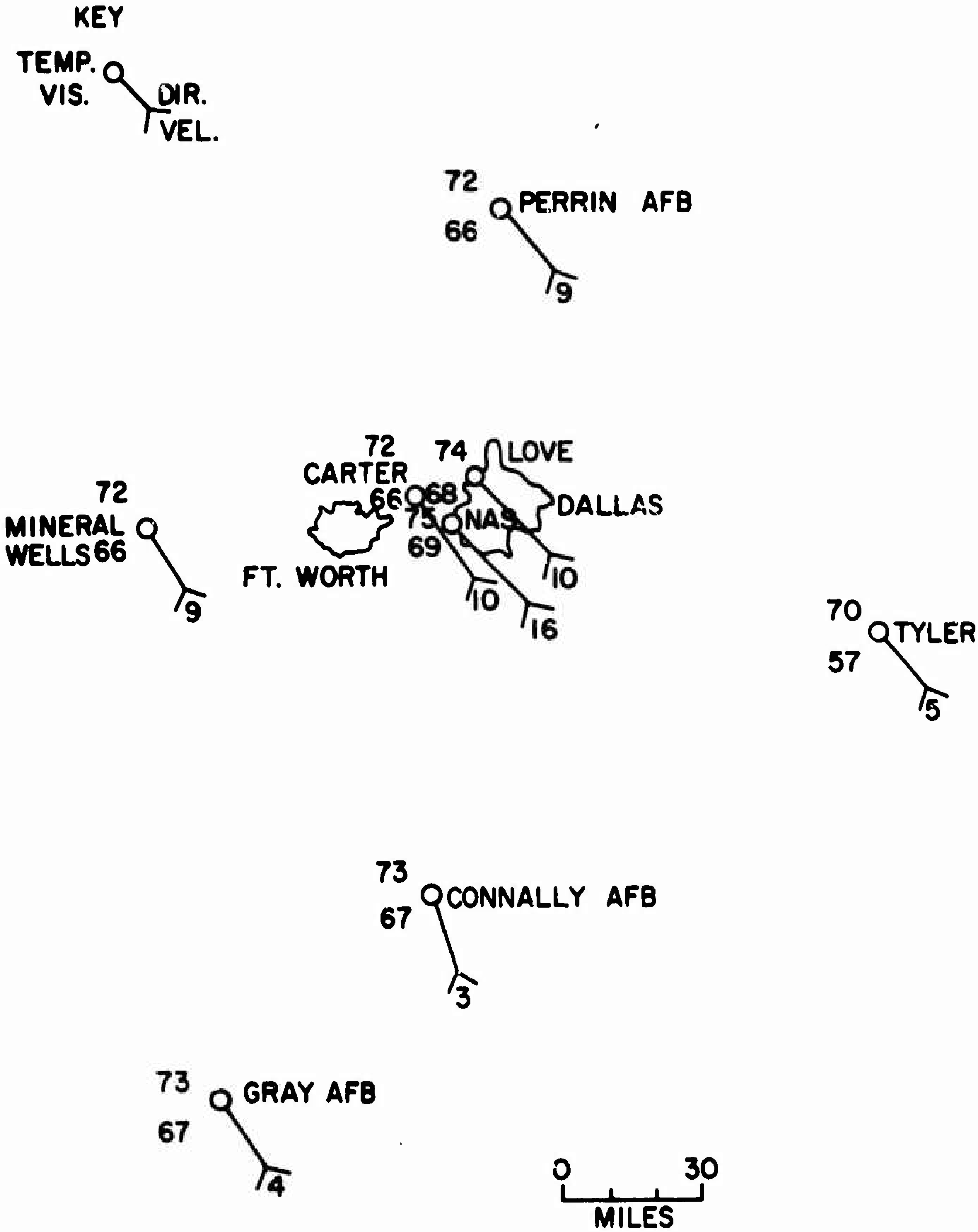


Fig. 1 Multiple Reports of Surface Wind, Temperature and Dew Point as Observed by Trained Weather Observers at 2:00 a.m., September 19, 1957.

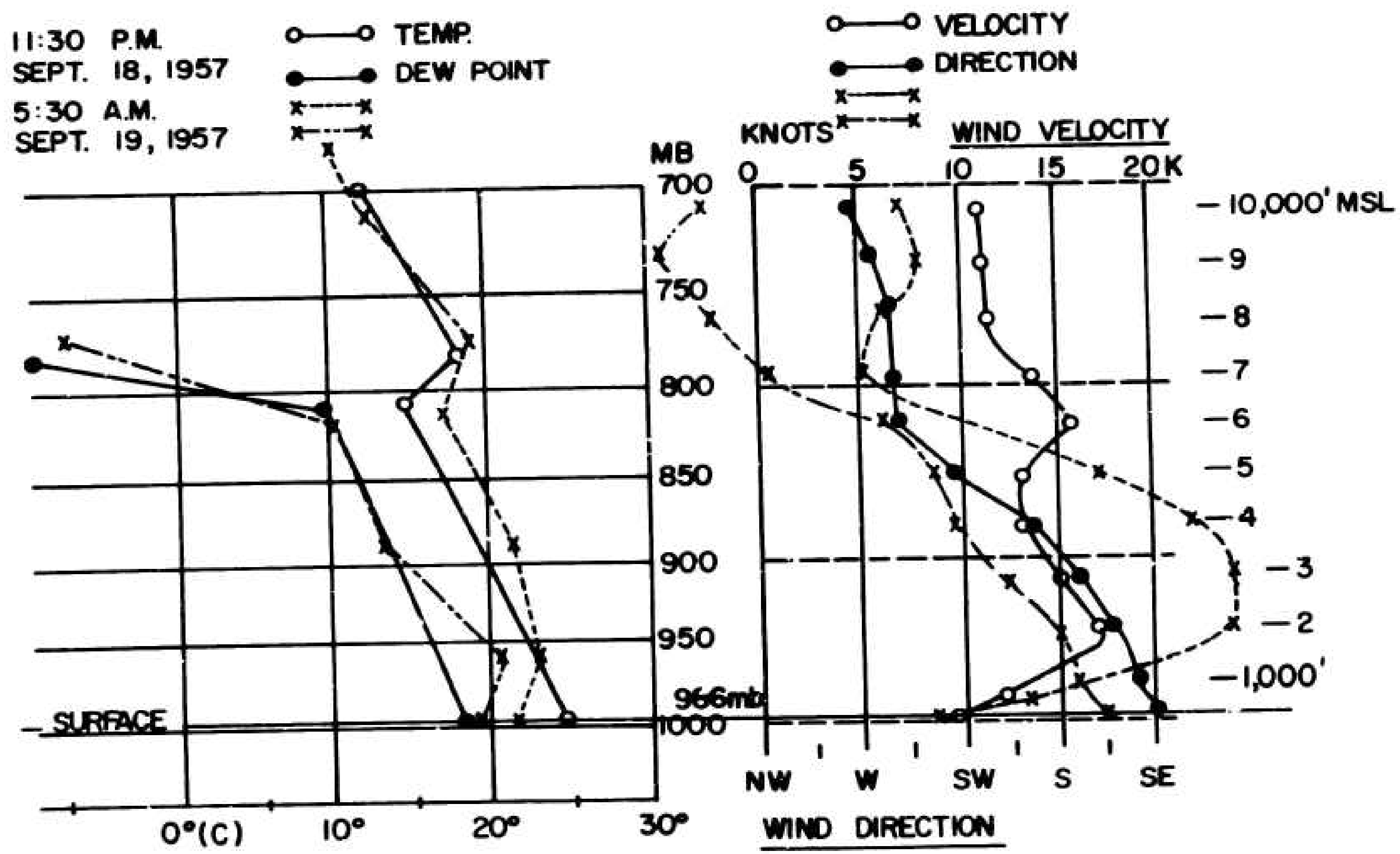


Fig. 2 Profiles of Temperature, Dew Point, Relative Humidity, Wind Direction and Velocity at Ft. Worth, Texas, during night and early morning hours, September 18-19, 1957.

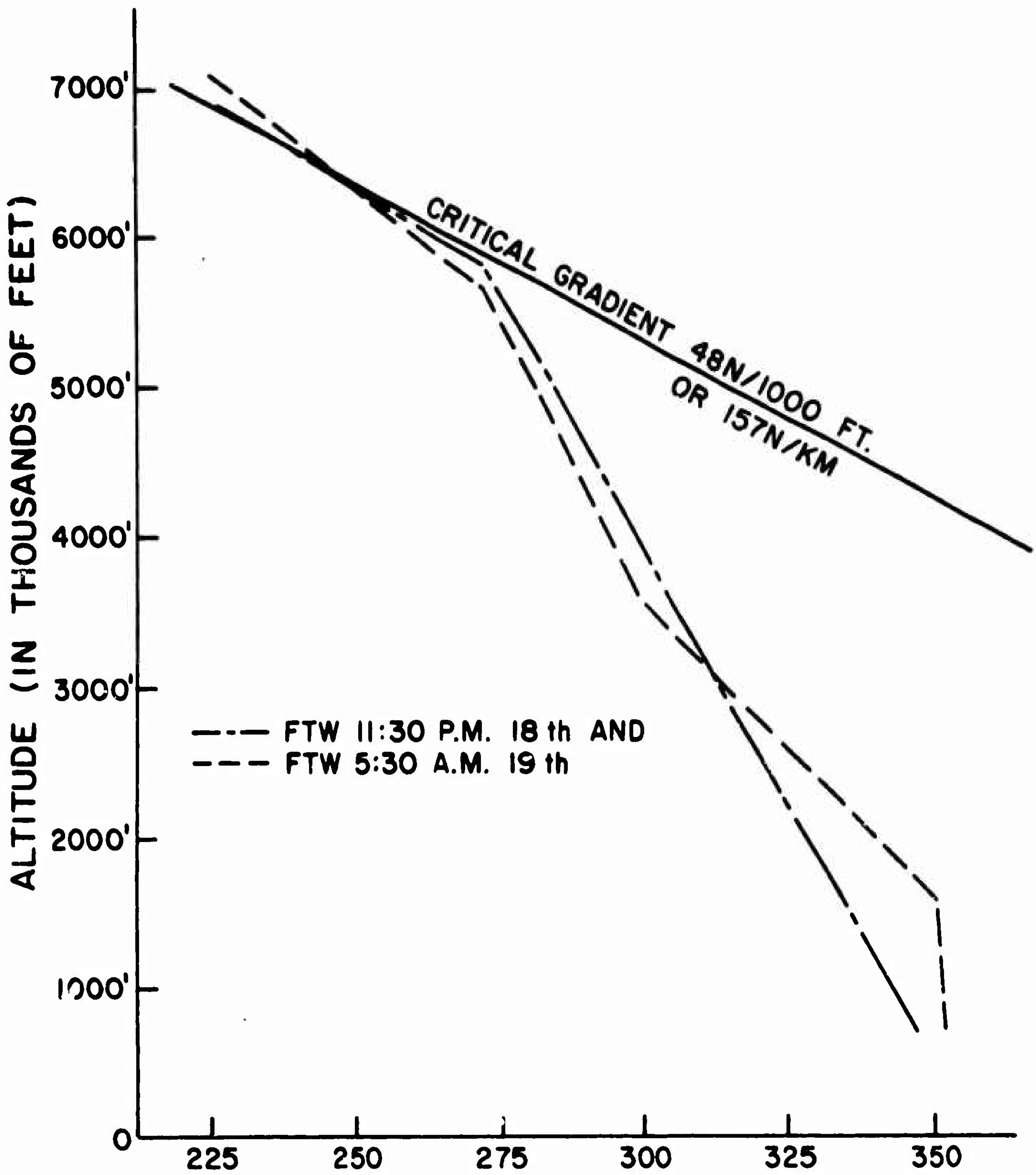


Fig. 3 Refractivity profiles at Ft. Worth, Texas, Carswell AFB, 11:30 p.m. September 18 and 5:30 a.m., September 19, 1957. Note critical gradient of N for microwave ducting in the vicinity of 6000 feet to 7000 feet altitude.

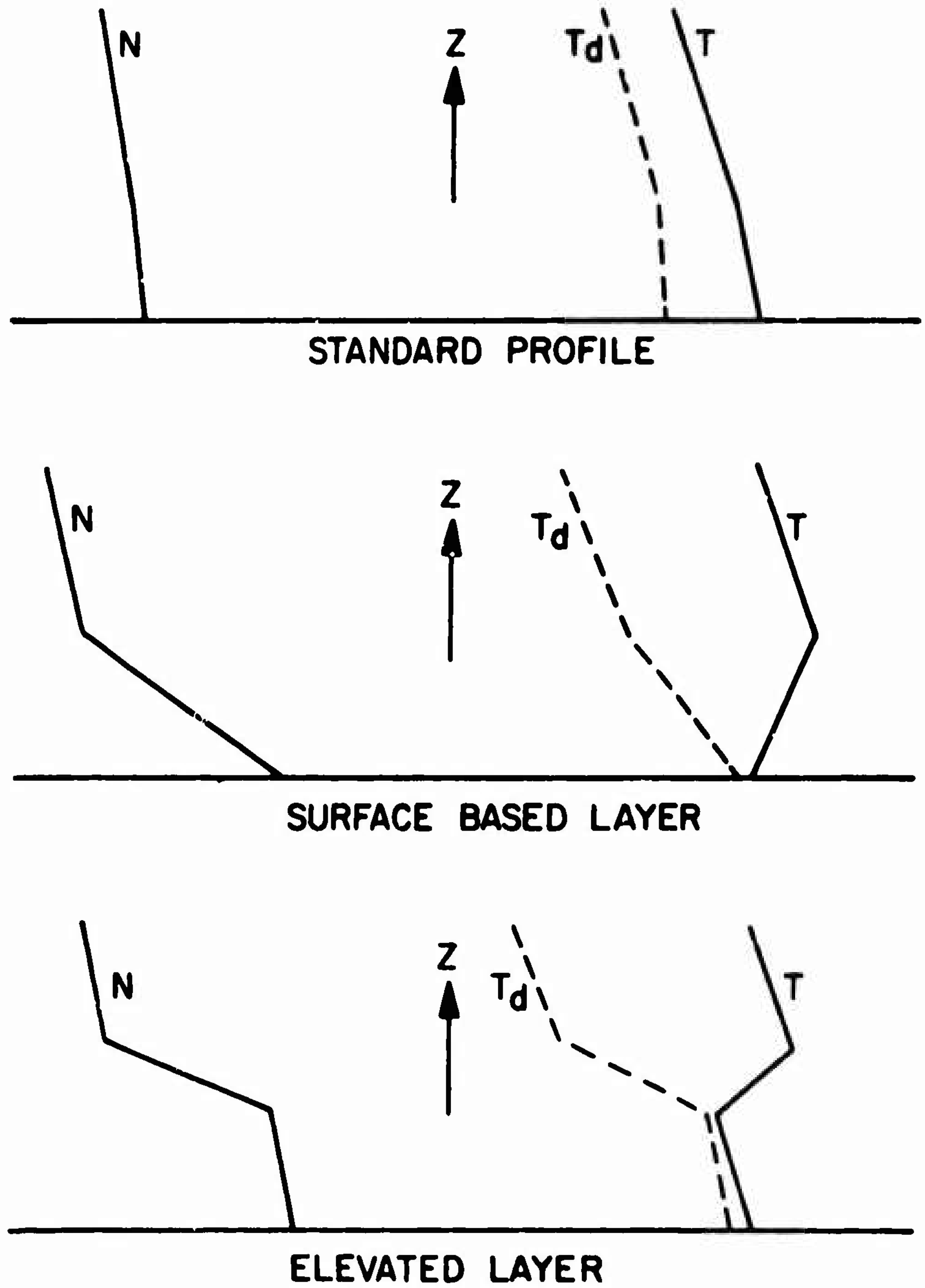


Fig. 4 Typical refractive index (N) profiles and sounding curves for three refractive index models. Solid curves on the right are for temperature--dashed curves for dew point temperature.

middle portion and the lower portion of Figure 4 indicate the corresponding effect on the change in refractive index with height as inversions are observed near the surface and at some elevated layer. In both of the non-standard patterns the gradient of N is somewhat greater than the critical value capable of producing ducting of microwave energy.

EXTRAORDINARY RADAR ECHOES

Of special importance in this investigation was some research work done at Texas A & M using their 3.2-Cm. AN/CPS-9 weather radar. The report, prepared by L. B. Cobb and V. E. Moyer, covers research carried out in 1962 and 1963, supported by National Science Foundation Grant NSF G-13834. This study was particularly interested in abnormal PPI presentations of radar echoes that occurred during clear weather.

The effect of atmospheric refraction on microwave propagation in the lower troposphere is a problem with which radio engineers and radio meteorologists have been vitally concerned since World War II. Prior to that time, the speed of propagation of electromagnetic energy had been considered to be a constant, that of the speed of light in a vacuum. As radar, missiles, and other radio-controlled equipment were developed and became more complex, evidence of small changes in the speed of propagation due to atmospheric conditions began to mount. These small changes in speed are very important as they cause refraction, or a change in the direction of propagation, of the electromagnetic energy. Radar trapping, errors in the positioning of targets, the radio hole, fading of radio signals, and "anomalous" echoes on weather radar scopes are some of the problems encountered. Any observer who makes critical deductions based on radar observations may be tricked into bad decidions unless he is familiar with the limitations of the equipment under nonstandard atmospheric conditions. Radar echoes of unknown origin near a vertical beam above the earth's surface are commonly called "angels". Unusual echoes from the surface are generally referred to as "anomalous propagation" or "AP". Both of these phenomena have been ascribed to abnormal refraction of the radio ray.

A study of abnormal radar echoes made at Texas A & M dealt primarily with anomalous propagation brought about by ducting or bending of radar beams due to inversions near the surface. They studied the expansion of ground clutter echoes due to increased gradient of refractive index near the surface. They examined large areas of anomalous echoes separated from the normal ground clutter pattern brought about by both strong surface inversions and strong upper level inversions.

The index of refraction, n, of electromagnetic energy in a non-dispersive medium such as the troposphere is defined as the ratio of the speed of propagation in a vacuum to the speed of propagation in the medium:

$$n = \frac{c_{vacuum}}{v_{air}} \qquad (1)$$

The speed of radar energy in the atmosphere is slightly less than the speed in a vacuum, so that the index of refraction always is very close to, but in excess of, unity. A typical example is 1.000287. For convience in handling, the index of refraction is converted to a

"refractive modulus," N, which is referred to most frequently as "refractivity":

$$N = (n - 1)10^6, \tag{2}$$

The refractivity for the above example would be 287.

The index of refraction is a function of temperature, pressure, and humidity, their relationship being given by the equation

$$N = (n - 1)10^6 = \frac{Ap}{T} + \frac{ABe}{T^2} \tag{3}$$

where p is the total atmospheric pressure in millibars, e is the partial pressure of atmospheric water vapor in millibars, T is the temperature in degrees Kelvin, and the constants A (= 76.6 deg/mb)* and B (= 4810 deg)* are average values recommended by Smith and Weintraub. A is the dielectric constant for dry air and B is the water vapor dipole moment. The formula is correct to within 0.5 per cent for the temperature range of -50C to 40C and the frequency range of 30 mc/sec to 30 kmc/sec. The actual amount of refraction is small, never exceeding a fraction of a degree; it is usually expressed in milliradians, or "mils." Therefore, radar operations will be influenced most when the angle between the refracting layer and the radar ray is very small.

Standard propagation occurs when the atmosphere is stratified vertically in such a way that a lapse of 12 N-units occurs in each 1000 ft. Under these conditions, a horizontal radar ray will be bent downward slightly due to increasing velocity aloft. This increase in velocity is very small; e.g., in the time it takes the horizontal ray to travel 1 mi at the surface, it will travel 1 mi. plus 3/4 in. at a height 1000 ft above the surface. This has the effect of extending the radar horizon about 15 per cent beyond the geometric horizon.

Nonstandard propagation will result when the temperature or water content of the atmosphere vary significantly from so-called "standard" values. Substandard refraction, i.e., less downward bending or possible actual upward bending of the radar ray, will occur if the refractivity is constant or increases with height. The propagation is superstandard if the refractivity decreases with height at a rate exceeding the standard rate. This causes an increased downward bending of the ray. If the velocity difference between the surface and 1000 ft achieves 3in./mi of horizontal travel, as occurs with a refractivity of -48N/1000 ft., a ray will have the same curvature as the earth with resultant greatly extended horizons, a condition referred to as "ducting."

Superrefraction normally results from a combination of increasing temperatures and decreasing humidities with height. Nocturnal radiational cooling at the surface and normal lack of nighttime convection will cause a temperature inversion, if other physical parameters are favorable. These

*slightly different than values presented by Bean and Dutton.

conditions are conducive to the formation of superrefractive strata in the lower troposphere. The formation of superrefractive strata is favored by clear skies and low wind speeds.

Elevated superrefractive layers also occur with temperature inversions or in stable layers in which there is a decrease in moisture with height. Subsidence inversions are the most common cause of this situation.

LOCAL TERRAIN SURROUNDING COLLEGE STATION, TEXAS

When the beam of a radar unit is used to cover a large horizontal area - from 200 to 300 miles - the elevation angle of the beam must be at or near zero. Near the radar site, even when the antenna is several feet above the ground, part of the energy is "echoed" back from nearby objects and/or the ground itself. As the energy goes farther and farther from the radar site the curvature of the earth permits the beam to extend into the air mass higher and higher above the earth's surface. The local terrain surrounding any particular radar location helps define the tpyical ground pattern. Figure 5 shows the topographic map of area within 150 miles of College Station, Texas.

NORMAL GROUND PATTERN

A standard pattern must be determined if one wishes to ascertain the degree of abnormality of nonstandard patterns. Figure 6 presents the PPI (Plan Position Indicator) pattern for College Station with the elevation angle set at 0^{o} and a full gain setting of the receiver. It is the ground return pattern associated with standard refraction in the atmosphere. The black circle shown in Figure 6 encloses an area inside 25 miles from the radar site at College Station (CCL). The terrain features in Figure 5 are reflected in this normal ground pattern. For example, the line of echoes oriented southwest - northeast (approximately 25 miles south of CLL) represents the ridge which rises south of Yegua Creek west of Navasota. The low ground along the three streams - Brazos River, Yegua Creek, Navasota River - is indicated by the converging blue lines which join to form the expanded Brazos River near Navasota before it heads southeastward to empty into the Gulf at Freeport.

Figure 6 can be reproduced with a 0^{o} beam angle and a near standard atmosphere day after day at College Station, Texas, and can be considered the normal ground pattern. A standard pattern must be determined if one wishes to ascertain the degree of abnormality of nonstandard patterns.

EXPANSION OF NORMAL GROUND PATTERN

Eleven cases were studied in which anomalous propagation caused an expansion of the normal ground pattern. The amount of additional echo observed varies from scattered, small additions to large areas of anomalous echoes which extend beyond the 50 mi range. The eleven cases were divided roughly according to whether they had small or large amounts of AP. Examples from each division are shown in Figures 7 and 8. The black circles enclose the same 25 mile radius area in these figures as in Figure 6.

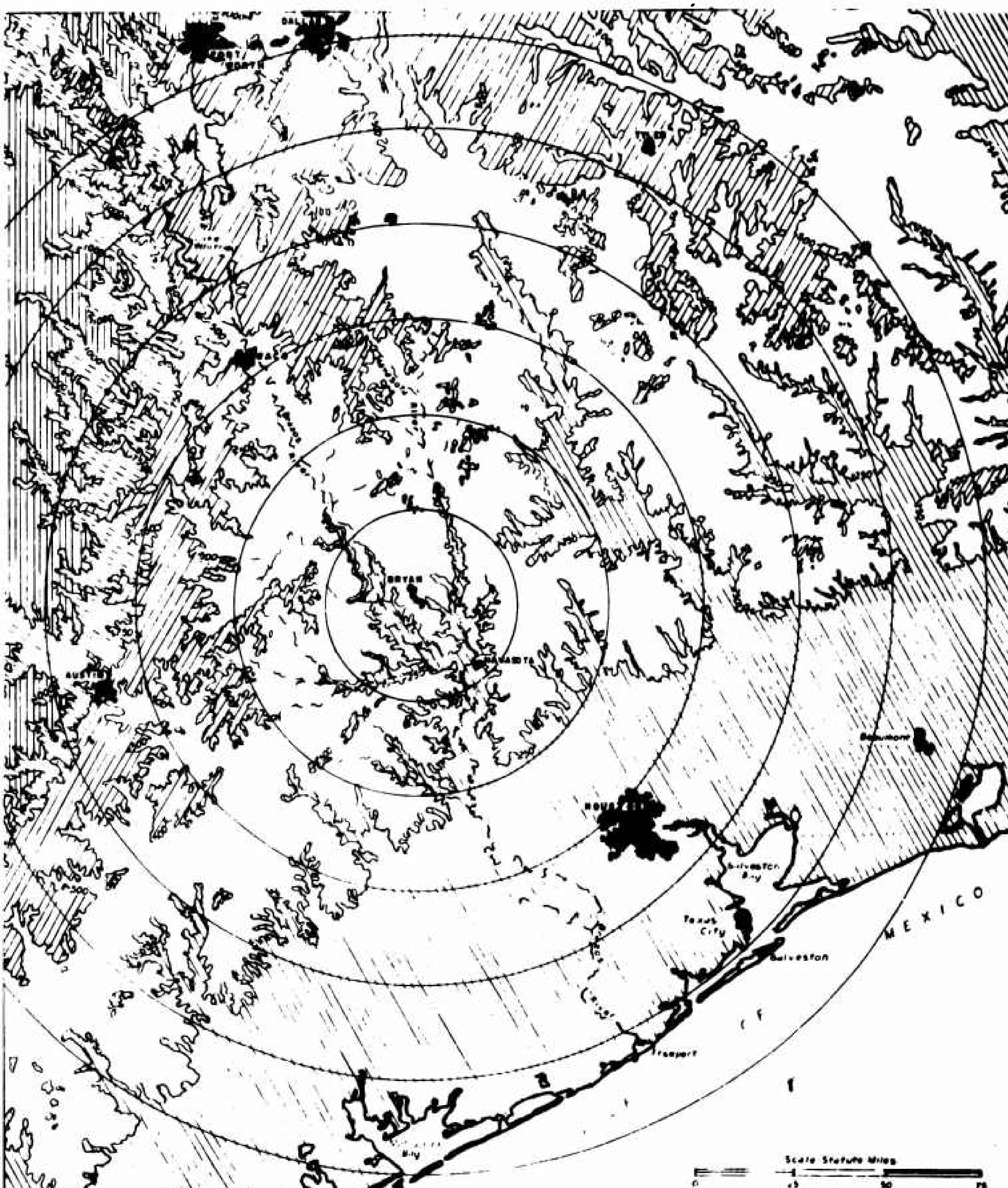
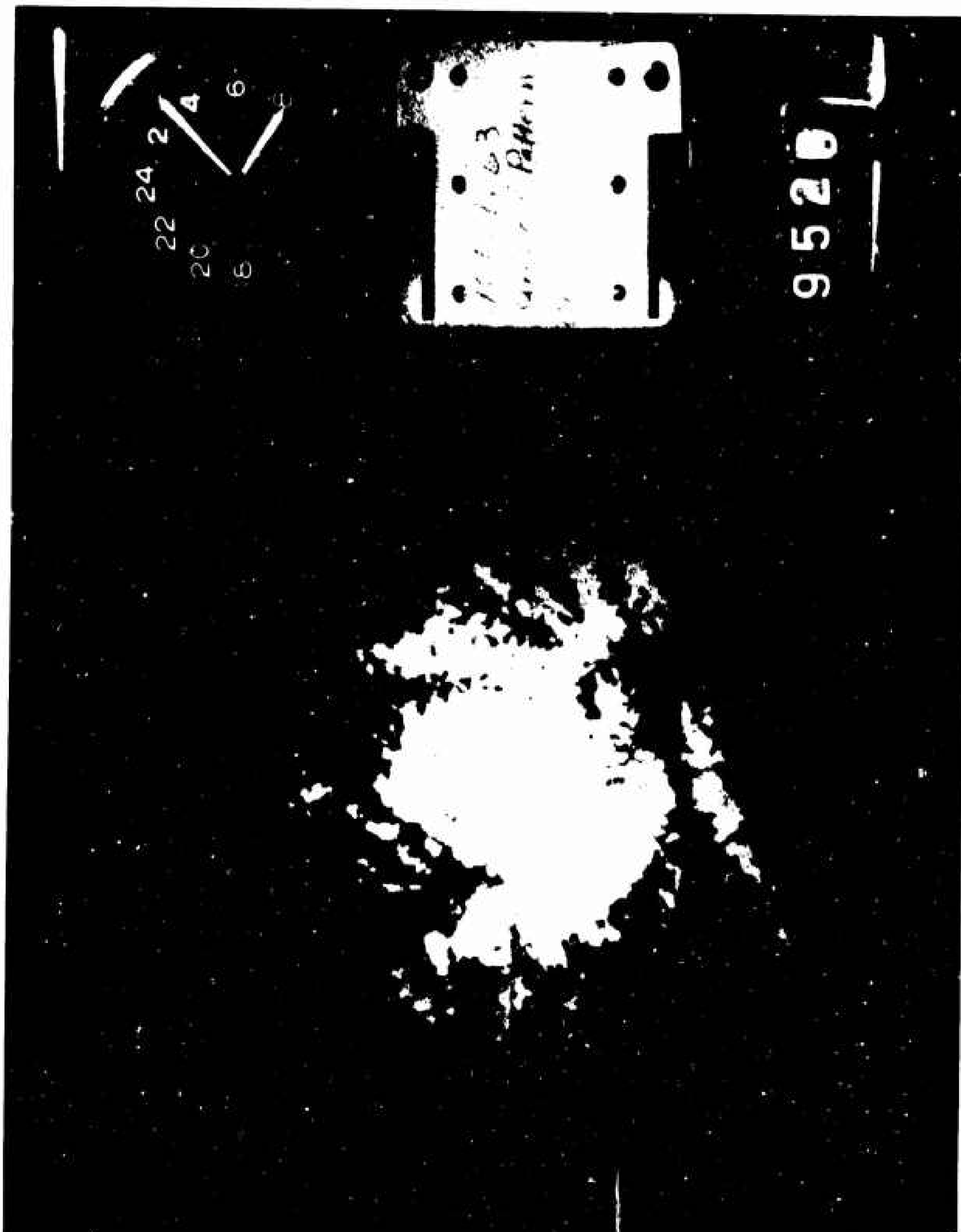


Fig. 5 Topographic Map of Area within 150-mi Radius of CLL.



0808CST 12 February 1963, Range: 50 mi.
Fig. 6 Normal Ground Pattern for AN/CPS-9 Radar located at CLL.

0843CST, 27 March 1962, Range: 50 mi.
Fig. 7 Expansion of Ground Pattern by Anomalous Echoes.

2320CST, 18 April 1962, Range: 50 mi.
Fig. 8 Expansion of Ground Pattern by Anomalous Echoes.

The common feature of all cases was a surface refracting layer less than 2000 ft thick, overlain by air of standard or near-standard refraction. The difference in refractivity between the two divisions is reflected in the extent to which the ground pattern is expanded. The smaller expansions of AP echoes are associated with smaller refractivity values, and larger amounts with larger values. All cases with greater amounts of AP were from periods of higher temperatures than those with lesser amounts. Warmer air masses, with their larger values of temperature and humidity, have greater values of refractivity. However, the gradient of N, rather than the discrete values of N, is most important in determining the refracting properties of an air mass.

The difference in amount of anomalous echoes appear to depend upon the gradient and thickness of the surface refracting layer. All of the smaller amounts occurred with gradients between 18N/1000 ft and 30N/1000 ft; the larger amounts occurred with gradients between 26N/1000 ft and 40N/1000 ft. In general, the refracting layer was thicker when the larger amounts of anomalous echoes were observed. However, the thickness of the surface refracting layer was less than 1600 ft in all cases.

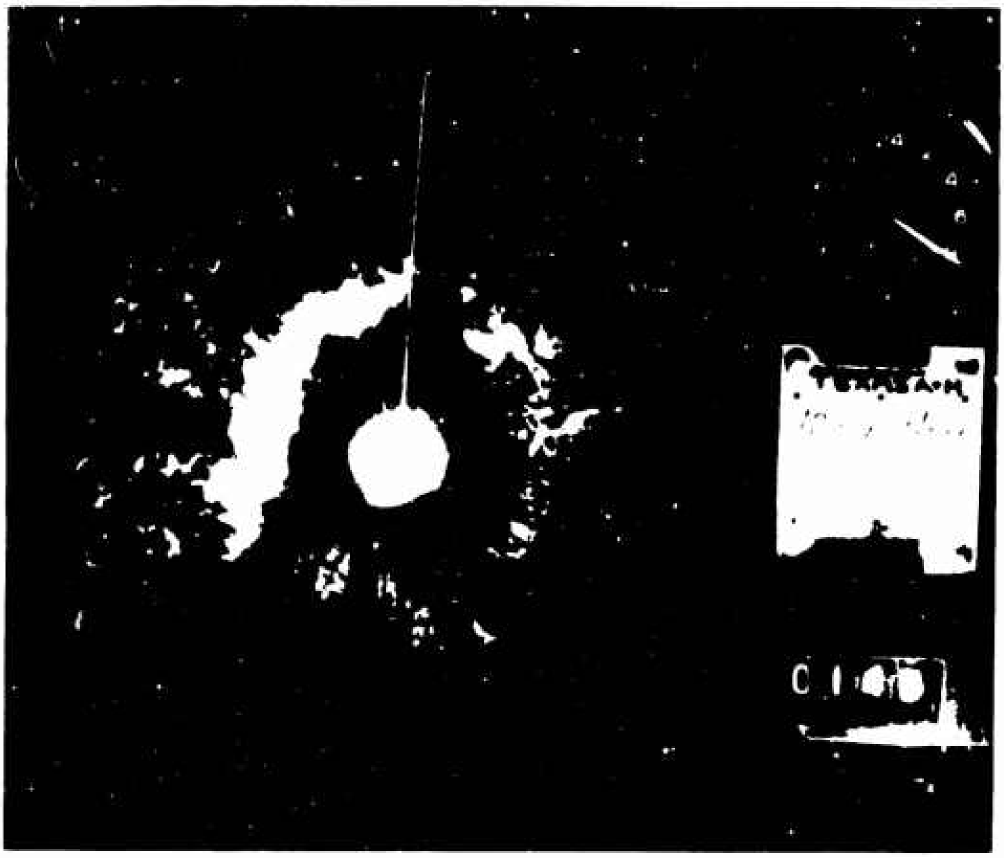
The anomalous echoes are related to the topographic features. Comparison of Figure 7 with a map of the terrain shows that the excess echoes (indicated by white arrows) are reflections from hills at those locations. These hills are not detected under standard refractive conditions, but are detected when the radar ray is bent one and one-half to two times the standard rate of bending. Greater bending of the ray will cause additional topographic features to be presented on the PPI (Figure 8).

LARGE AREAS OF ECHO SEPARATED FROM THE NORMAL GROUND PATTERN

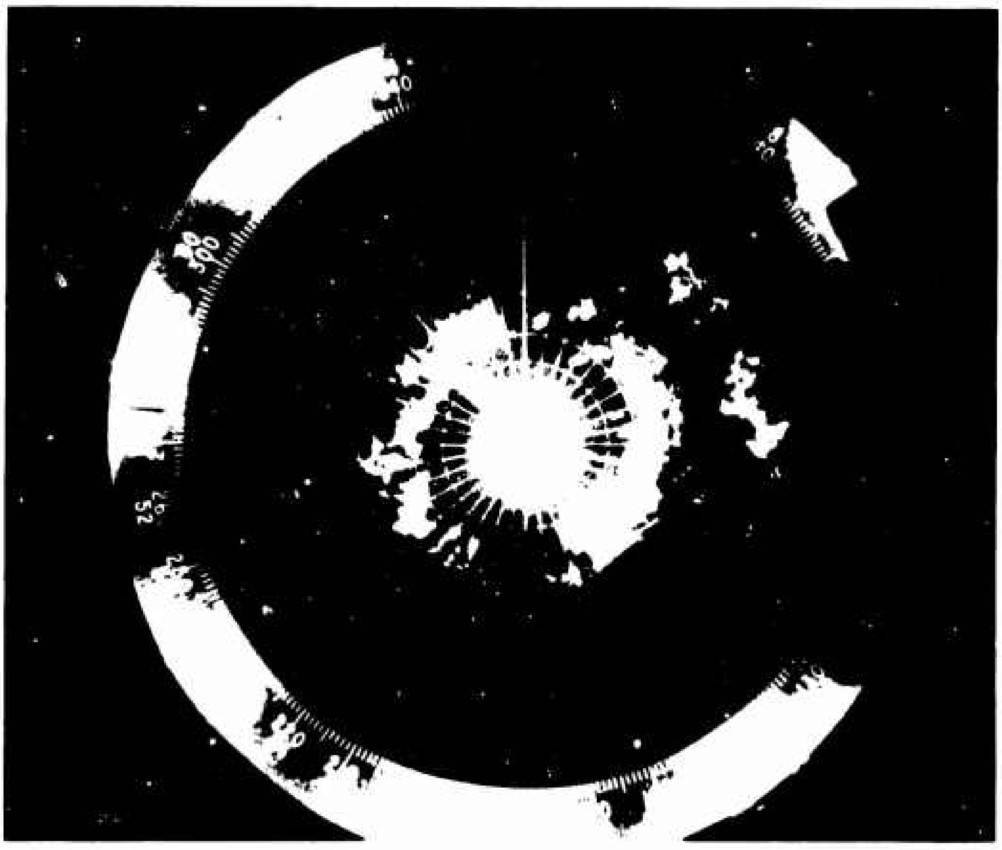
The examples that are included in this group are those which have anomalous echoes at a considerable distance from the normal ground pattern. In some cases, these echoes encircle the local area; in others, they are confined to one or two quadrants. In most cases, they appear to be caused by an elevated ducting layer.

Two examples of anomalous echoes which encircle the local area are considered first. Figures 9 and 10 are examples of "radial patterns" which occurred on 7 May 1962 and 12 February 1962. The black circles again show an area of 25 miles radius nearest CLL. A polaroid photograph is presented for 7 May because the regular photographs were not useable. In the case of 12 February, there had been a complete ring of echoes earlier, but those in the eastern quadrants had begun to disappear by 0820CST, when the photograph was taken. The refractivity profiles for both dates were very similar.

A large anticyclone was located over the Gulf of Mexico at the surface, with a smaller high-pressure area aloft centered over Texas, on both 7 May 1962 and 12 February 1962. Thus, there was a layer of moist Gulf air near the surface, overlain by a very dry layer caused by subsidence. Nocturnal radiational cooling at the surface, together with the subsidence warming aloft, created a very sharp inversion. These are the ideal conditions for the formation of an elevated superrefractive layer, with



a. 0820CST, 7 May 1962, Range: 300 mi.
Fig. 9 Radial Pattern of Anomalous Echoes Associated with an Elevated Refracting Layer.



b. 0820CST, 12 February 1962, Range: 225 mi.
Fig. 10 Radial Pattern of Anomalous Echoes Associated with an Elevated Refracting Layer.

near-standard refractive conditions above and below the layer. The effect of the elevated layer on the radar ray is dependent on the location of the antenna relative to the layer, and on the antenna elevation angle. If the antenna is located well below the layer, total bending of the ray may be considerable at low elevation angles, but the ray will emerge on the top side of the layer. When the antenna is located just below the layer (within several thousand feet) and elevated less than 2 deg, the ray may be trapped or totally refracted.

There are several characteristics which distinguish these echoes from those discussed previously. First, a radial pattern is caused by total or near-total refraction from an elevated layer, so that its location is dependent on the vertical distance between the radar and the layer, as well as on the antenna elevation angle. Terrain features are of secondary importance in giving the pattern its shape and location. Second, these echoes usually persist longer because it takes much more convective mixing to destroy an elevated layer than is needed to destroy a layer next to the surface. Third, elements of a second ring of echoes are often observed; they probably result from a second "bounce" of the ray between the surface and the refracting layer.

A good example of anomalous echoes associated with the formation of an elevated refracting layer occurred during the night of 27 April 1962. An elongated low-pressure trough aloft, extending from Illinois to central Texas, triggered severe thunderstorms as it moved eastward during the day. Clearing occurred over the southern half of the state during the afternoon, but thunderstorms continued in the Dallas-Shreveport area. Moist Gulf air was flowing northward aloft, ahead of the trough, at the time of the 0000UT radiosonde soundings; it was replaced by very dry air from the west after passage of the trough. Figure 11 shows the refractivity profiles for S n Antonio (SAT) and Lake Charles (LCH) at 0000 Universal Time (UT) and 1200UT, 28 April (1800CST, 27 April and 0600CST; 28 April); the profile for Ft. Worth (ACF) is not shown as it did not change appreciably from one sounding to the next. The formation of an elevated superrefractive layer is clearly indicated at both stations between the times of the two soundings. Figure 12 shows the AP echoes which had formed in the southern quadrants by 2250CST (skies were then clear); the echoes to the north were caused by thunderstorms.

The last example to be considered in this group occurred on 9 February 1962 (Figure 13a--e). Skies were generally clear over the state, except for some early morning fog along the coast and low stratus clouds which dissipated as the temperature increased. A large high-pressure area was situated over the southeastern United States, so that warm, moist air was flowing northward from the Gulf at the lower levels. Cold, dry air aloft had entered Texas from the northwest; the 1200UT refractivity profiles Figure 14) indicate that this air had not reached LCH. Very strong superrefractive layers existed at ACF and SAT; it appears to be a reasonable assumption that such a layer existed at CLL also, if one considers the amount of anomalous echoes that were occurring (Figure 13a---e). Both the profiles and the photographs demonstrate that the pattern was not a true radial pattern at 0850CST, although echoes occurred in all directions. During the next 15 min, heating and convective mixing began to destroy

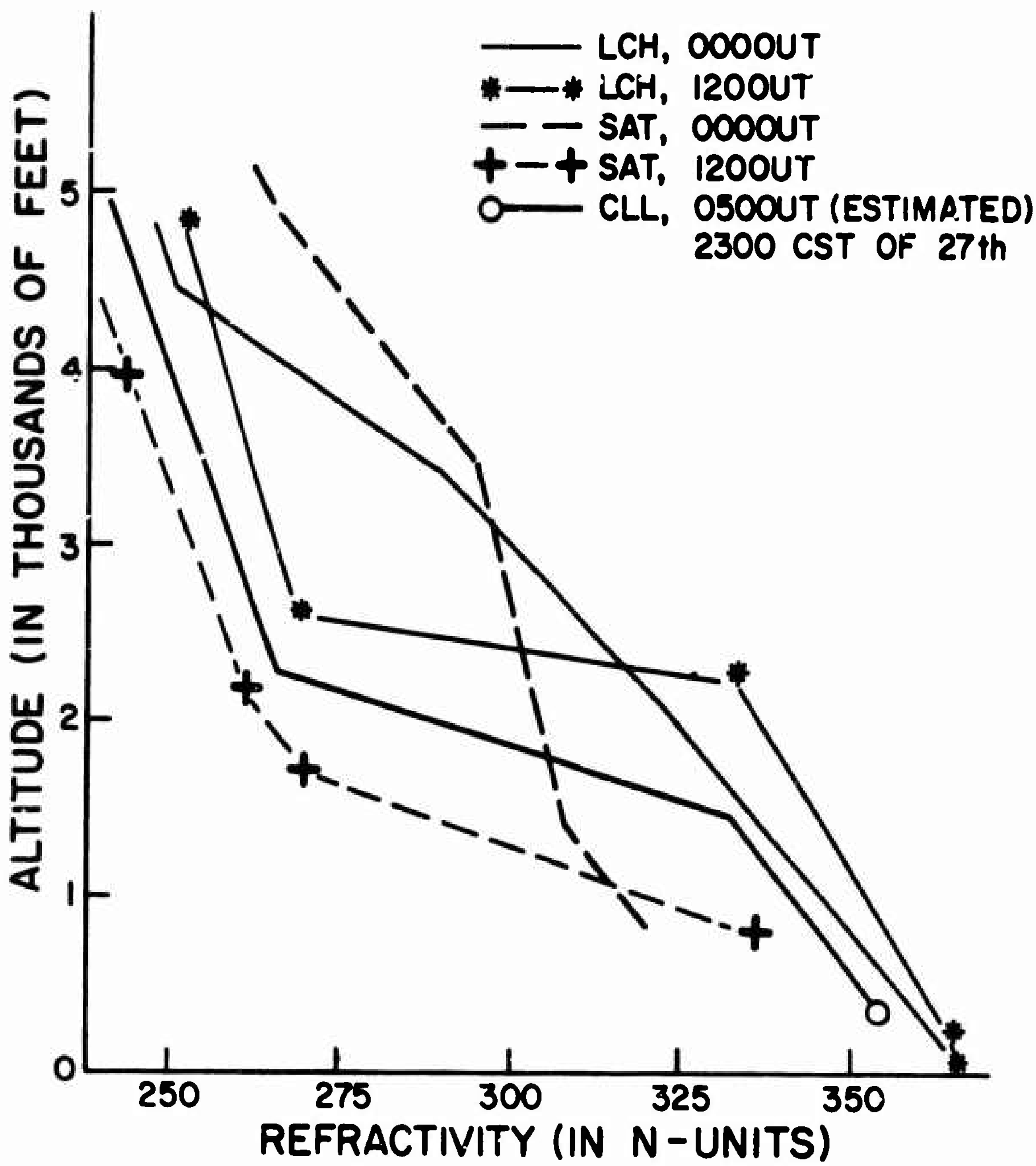
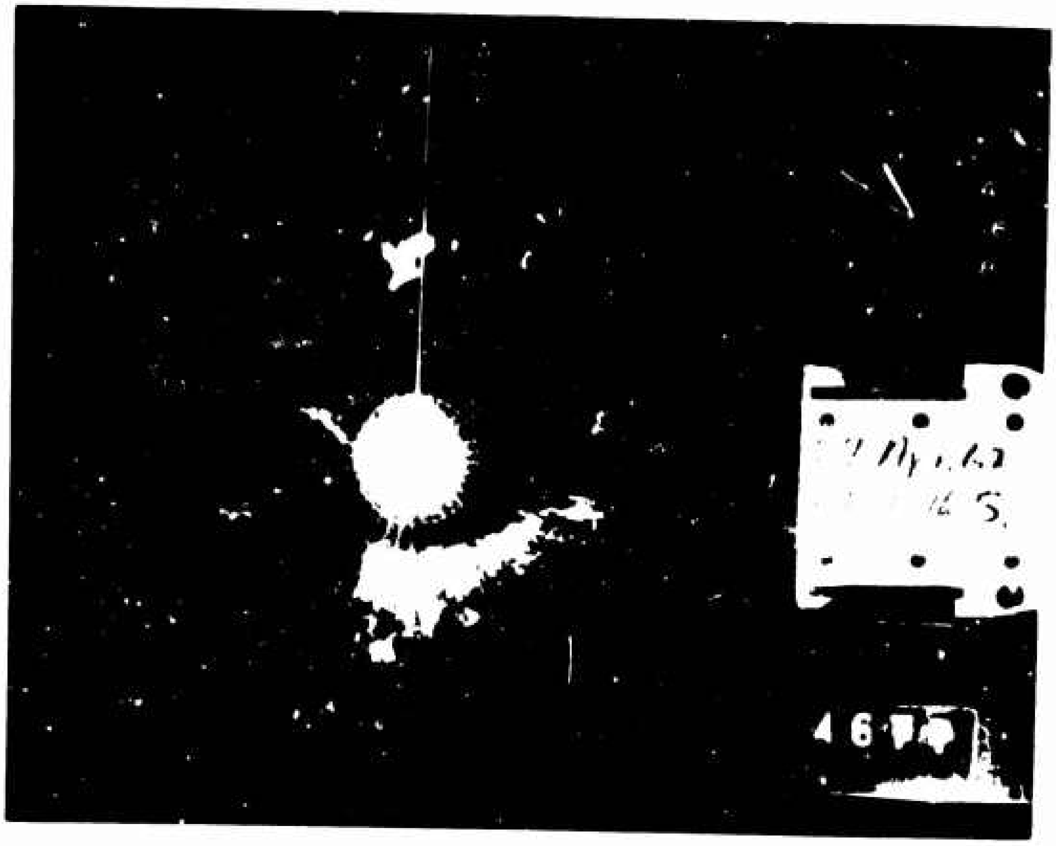


Fig. 11 Refractivity Profiles for 0000UT and 1200UT, 28 April 1962.



2250CST, 27 April 1962, Range: 300 mi.
Fig. 12 Anomalous Echoes Associated with the Formation of an Elevated Refracting Layer.

a. 0850CST, 9 February 1962, Range: 300 mi.
Fig. 13a Anomalous Echoes caused by a Strong Super-refractive Layer at the Surface.

b. 0905CST, 9 February 1962, Range: 300 mi.

c. 0931CST, 9 February 1962, Range: 300 mi.

Fig. 13b & c. Anomalous Echoes caused by a Strong Super-refractive Layer at the Surface.

d. 0944CST, 9 February 1962, Range: 300 mi.

e. 1018CST, 9 February 1962, Range: 300 mi.

Fig. 13d & e. Anomalous Echoes caused by a Strong Super-refractive Layer at the Surface.

the superrefractive layer next to the surface; an elevated layer was created and the echoes moved outward from the center (Figure 13b). Continued heating and convection during the next 26 min destroyed much of the radial pattern (Figure 13c, 0931CST); in the following 13 min, all the echoes in the northwest quadrant disappeared and new echoes appeared in the southwest quadrant (Figure 13d, 0944CST). Nearly all the echoes had disappeared by 1021 CST, except several in the eastern quadrants beyond 100 mi, indicating that the low-level refracting layer was virtually destroyed. This example tends to confirm all previous conclusions concerning the relationship between anomalous echoes and the location and strength of superrefractive layers.

OPTICAL AND RADIO PROPAGATION

In Chapter 13 of the Handbook of Geophysics for Air Force Designers, published by the U. S. Air Force in 1957, various equations, tables, and nomograms are presented covering electromagnetic wave propagation in the lower atmosphere. Figures 15 and 16, as copied from that book, show how refractive modulus values vary with altitude for both optical and radio wavelengths. As shown in Figure 16 the two curves for optical and radio wavelengths converge at altitudes greater than 20,000 feet. This would indicate that any abnormal ducting of optical and/or radar type images might be similarly distorted to observers in aircraft flying above 20,000 feet when atmospheric abnormalities are uniquely favorable for anomalous propagation.

AIRCRAFT PENETRATION OF CLEAR AIR "ANGELS"

At the Ninth Weather Radar Conference in Kansas City in 1961, R. Q. Tillman, R. E. Ruskin, and M. N. Robinson of the U. S. Naval Research Laboratory, reported on the tracking of approximately 500 clear air "angel" echoes. Most of the "angels" plotted had radar cross sections between approximately 0.2 and 3 cm^2.

The maximum detectable range usually fell between 2,000 and 4,000 yards. On occasion, distinct angels with the appearance and characteristics of large airplanes or vessels were tracked, presenting targets roughly 100 times the minimum detectable target at that range. The physical extent of most of the angels, as deduced from manually varying the range setting across the target, was approximately 35 yards.

A series of attempts was made to vector an instrumented WV-2 Super-Constellation aircraft through the apparent location of the angel echoes. Of 28 attempts, 4 were successful. The plane was directed by radio by the radar operators, using the altitude and heading information from the plotting boards. On the four successful runs the plane passed directly through the telescope cross hairs, and its radar return was visible in the range notch of the A-scopes. In each case the radar shifted to this stronger target. However, in one run it was possible to unlock momentarily from the plane and to pick up the angel again. On another occasion, the angel echo disappeared when the aircraft passed through. The aircraft instrumentation included: a rapid-response refractometer, a vortex thermometer, electric field and conductivity instruments, and space charge detector. In none of the four instances was there any correlation between

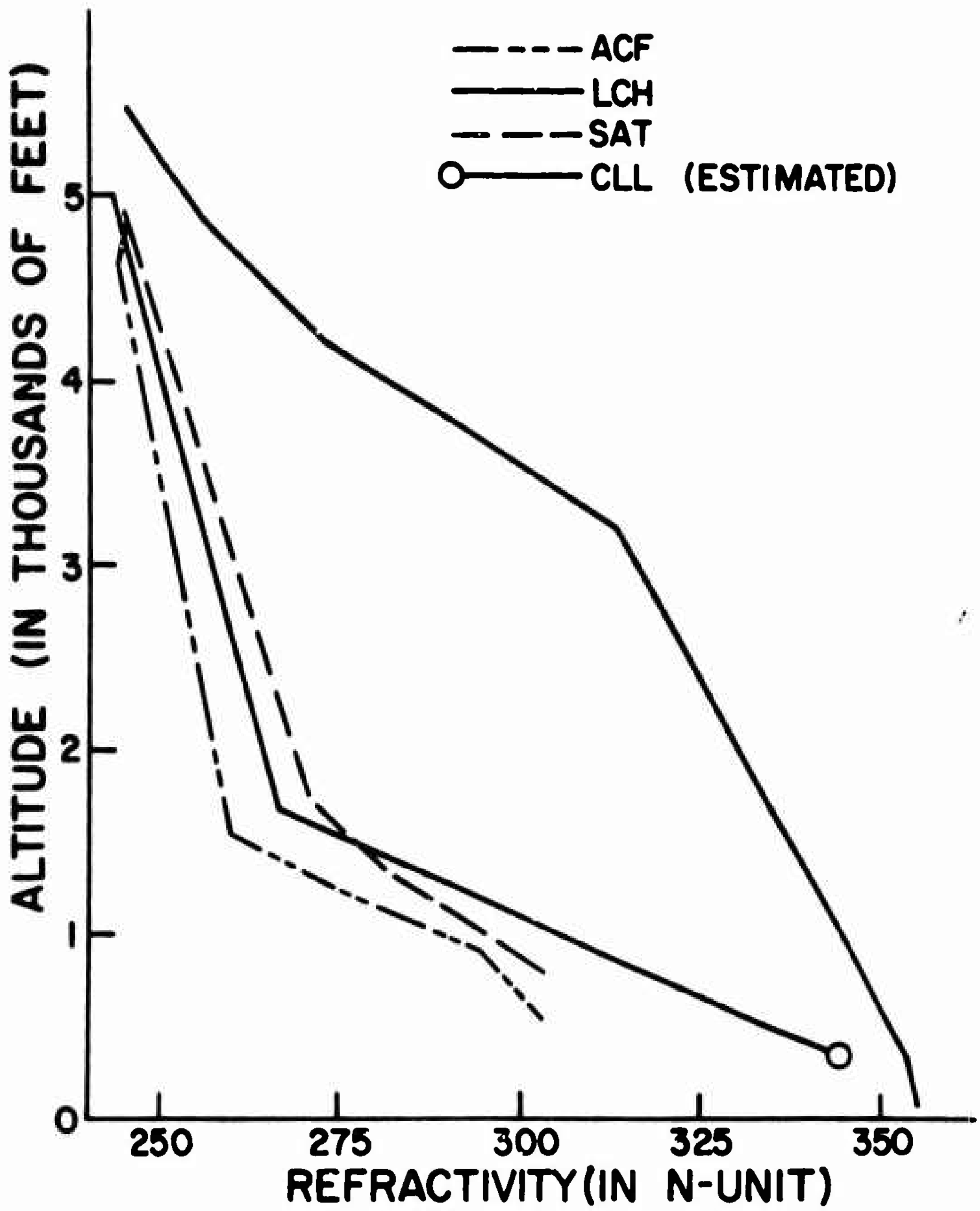


Fig. 14 Refractivity Profiles for 1200UT, 9 February 1962.

the records of these instruments and the angel location. Slight turbulence was encountered in close proximity of several of the angels, but no definite correlation could be ascertained.

SUMMARY

Cloudless skies and good visibility prevailed at the time of the UFO sightings in an area from 50 miles east of Dallas to Mineral Wells, Texas in the early morning hours of September 19, 1957. Therefore, the UFO sightings were not related to cloudiness, lightning, or radar echoes from shower activity near the flight path.

The vertical profile of the atmosphere as measured at Ft. Worth did contain a sharp temperature inversion near the 6000 - 7000 foot level (Figure 2). The temperature increased and moisture content decreased rapidly with height in this layer. The change with height was great enough to permit a corresponding gradient of refractive index near the critical level which allows extensive anomalous propagation of either optical or radar energy (see Figures 3 and 16). The aircraft crew, although flying above the ducting layer, could have been receiving echoes and/or images of objects or lights many miles from the path of the aircraft. The ground operators of radar, located below the ducting layer, probably were observing echoes which were part of an anomalous propagation pattern transmitted to them due to the elevated refracting layer.

The air mass itself would have been changing slowly with respect to time during the night time hours. From a fixed position the ground radar operators would have been able to detect anomalous propagation near one particular position for fairly long periods. By contrast the airborne equipment would have been constantly changing its position relative to both the surrounding atmosphere and terrain. The probable ducting of images from considerable distances through the layered atmosphere would have tended to keep the images in the same general direction from the aircraft and at some distance away from the aircraft itself. This is in some ways similar to the observation of a rainbow from a moving automobile.

It is worthy to note that a large fraction of the reports on detailed research which have been used as references for the conclusions in this study have publication dates after September 1957. Even in 1968 it is not likely that the results of such research are common knowledge to a high fraction of aircraft crews who might on rare occasions fly near a "ducting layer" which is invisible in a cloudless atmosphere.

The detailed observations are being retained in my files. Should they be of further use to you please let me know.

LWC:dd

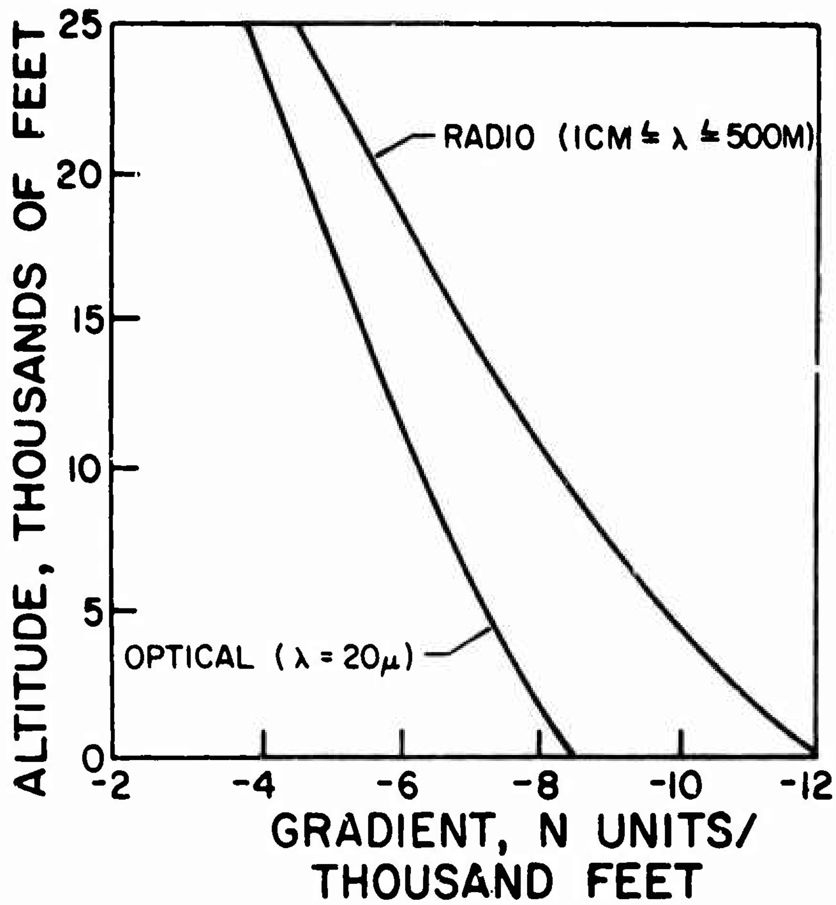


Fig. 15 Variation of Standard Gradient of Refractive Modulus with Altitude.

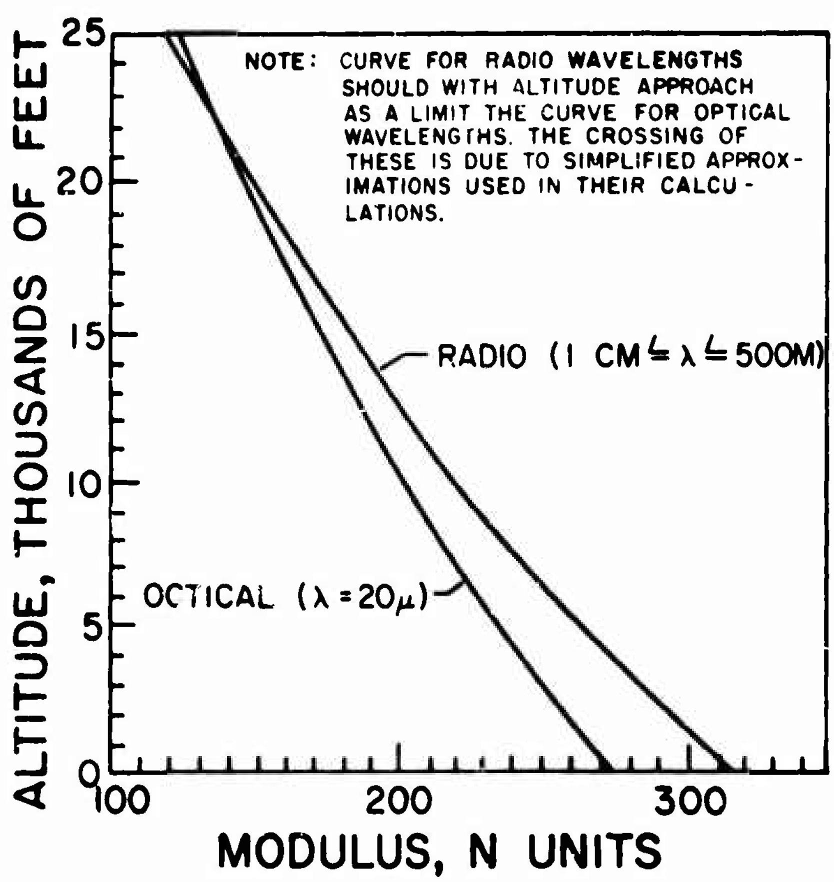


Fig. 16 Variation of Standard Refractive Modulus with Altitude.

APPENDIX R: LETTER FROM GENERAL N. F. TWINING
TO COMMANDING GENERAL, ARMY AIR FORCES
23 SEPTEMBER 1947

SUBJECT: AMC Opinion Concerning "Flying Discs" 23 September 1947

TO: Commanding General
Army Air Forces
Washington 25, D. C.
ATTENTION: Brig. General George Schulgen
AC/AS-2

1. As requested by AC/AS-2 there is presented below the considered opinion of this Command concerning the so-called "Flying Discs". This opinion is based on interrogation report data furnished by AC/AS-2 and preliminary studies by personnel of T-2 and Aircraft Laboratory, Engineering Division T-3. This opinion was arrived at in a conference between personnel from the Air Institute of Technology, Intelligence T-2, Office, Chief of Engineering Division, and the Aircraft, Power Plant and Propeller Laboratories of Engineering Division T-3.

2. It is the opinion that:

a. The phenomenon reported is something real and not visionary or fictitious.

b. There are objects probably approximating the shape of a disc, of such appreciable size as to appear to be as large as man-made aircraft.

c. There is a possibility that some of the incidents may be caused by natural phenomena, such as meteors.

d. The reported operating characteristics such as extreme rates of climb, maneuverability (particularly in roll), and action which must be considered evasive when sighted or contacted by friendly aircraft and radar, lend belief to the possibility that some of the objects are controlled either manually, automatically or remotely.

e. The apparent common description of the objects is as follows:

(1) Metallic or light reflecting surface.

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Basic Ltr fr CG, AMC WF to CG, AAF, Wash. D.C. subj "AMC Opinion Concerning "Flying Discs"

(2) Absence of trail, except in a few instances when the object apparently was operating under high performance conditions.

(3) Circular or elliptical in shape, flat on bottom and domed on top.

(4) Several reports of well kept formation flights varying from three to nine objects.

(5) Normally no associated sound, except in three instances a substantial rumbling roar was noted.

(6) Level flight speeds normally above 300 knots are estimated.

f. It is possible within the present U. S. knowledge -- provided extensive detailed development is undertaken -- to construct a piloted aircraft which has the general description of the object in subparagraph (e) above which would be capable of an approximate range of 7000 miles at subsonic speeds.

g. Any developments in this country along the lines indicated would be extremely expensive, time consuming and at the considerable expense of current projects and therefore, if directed, should be set up independently of existing projects.

h. Due consideration must be given the following: -

(1) The possibility that these objects are of domestic origin - the product of some high security project not known to AC/AS-2 or this Command.

(2) The lack of physical evidence in the shape of crash recovered exhibits which would undeniably prove the existence of these objects.

(3) The possibility that some foreign nation has a form of propulsion possibly nuclear, which is outside of our domestic knowledge.

3. It is recommended that:

a. Headquarters, Army Air Forces issue a directive assigning a priority, security classification and Code Name for a detailed study of this matter to include the preparation of complete sets of all available

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and pertinent data which will then be made available to the Army, Navy, Atomic Energy Commission, JRDB, the Air Force Scientific Advisory Group, NACA, and the RAND and NEPA projects for comments and recommendations, with a preliminary report to be forwarded withing 15 days of receipt of the data and a detailed report thereafter every 30 days as the investigation develops. A complete interchange of data should be effected.

4. Awaiting a specific directive AMC will continue the investigation within its current resources in order to more closely define the nature of the phenomenon. Detailed Essential Elements of Information will be formulated immediately for transmittal thru channels.

N. F. TWINING
Lieutenant General, U. S. A.
Commanding

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APPENDIX S: DIRECTIVE - MAJOR GENERAL L. C. CRAIGIE TO COMMANDING GENERAL WRIGHT FIELD (WRIGHT-PATTERSON AFB) - DISPOSITION AND SECURITY FOR PROJECT "SIGN", DATED 30 DECEMBER 1947.

(COPY)

30 December 1947

SUBJECT: Flying Discs

TO: Commanding General
Air Material Command
Wright Field, Dayton, Ohio
Attn: TSDIH

1. Reference is made to three inclosures, memoranda from your office to this headquarters, subject as above.

2. It is Air Force policy not to ignore reports of sightings and phenomena in the atmosphere but to recognize that part of its mission is to collect, collate, evaluate and act on information of this nature.

3. In implementing this policy, it is desired that the Air Material Command set up a project whose purpose is to collect, collate, evaluate and distribute to interested government agencies and contractors all information concerning sightings and phenomena in the atmosphere which can be construed to be of concern to the national security. It is desired that appropriate recommendations be forwarded to this Headquarters, wherever action is indicated which falls outside the field of the Air Material Command.

4. It is suggested that the activities of this project include the preparation and distribution of an initial report, as recommended in Inclosure 1, and that subsequent reports be issued on a quarterly basis. Supplementary reports should be issued at more frequent intervals should the need for same be indicated. This project is assigned priority 2A, with a security classification of "restricted" and Code Name of "SIGN". Where data of a classification higher than restricted is handled by the project such data should be classified accordingly. A complete interchange of data should be effected as recommended in Inclosure 1.

such data should be classified accordingly. A complete interchange of data should be effected as recommended in Inclosure 1.

BY COMMAND OF THE CHIEF OF STAFF:

L. C. CRAIGIE
Major General, U.S.Air Force
Director of Research and Development
Office, Deputy Chief of Staff, Material

4 Incls
1. Memo dtd 23 Sept '47 from AMC to AC/AS-2 (Gen Schulgen)
2. Memo dtd 24 Sept '47 from AMC to AC/AS-2 (Gen McDonald)
3. Memo dtd 19 Dec '47 to Gen Craigie
4. R&R from Dir of Intell. w/2 Dools

APPENDIX T: G. E. VALLEY, INTERPRETATION OF REPORTS OF UNIDENTIFIED FLYING OBJECTS, PROJECT "SIGN", NO. F-TR-2274-IA, APPENDIX "C".

Appendix "C"

Some Considerations Affecting the Interpretation of Reports of Unidentified Flying Objects

By

G. E. Valley, Member Scientific Advisory Board,
Office of the Chief of Staff, United States Air Force

The writer has studied summary abstracts and comments pertaining to unidentified flying objects, which were forwarded by Air Force Intelligence. These remarks are divided into three main parts: the first part is a short summary of the reports; the second part consists of a general survey of various possibilities of accounting for the reports; the third part contains certain recommendations for future action.

PART I -- SHORT SUMMARY OF OBSERVATIONS

The reports can be grouped as follows:

Group 1 -- The most numerous reports indicate the daytime observation of metallic disk-like objects, roughly in diameter ten times their thickness. There is some suggestion that the cross section is assymetrical and rather like a turtle shell. Reports agree that these objects are capable of high acceleration and velocity; they often are sighted in groups, sometimes in formation. Sometimes they flutter.

Group 2 -- The second group consists of reports of lights observed at night. These are also capable of high speed and acceleration. They are less commonly seen in groups. They usu lly appear to be sharply defined luminous objects.

Group 3 -- The third group consists of reports of various kinds of rockets, in general appearing somewhat like V-2 rockets.

Group 4 -- The fourth group contains reports of various devices which, in the writer's opinion, are sounding balloons of unusual shape such as are made by the General Mills Company to Navy contract.

Group 5 -- The fifth group includes repo .s of objects in which little credence can be placed.

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General Remarks

In general, it is noted that few, if any, reports indicate that the observed objects make any noise or radio interference. Nor are there many indications of any material affects or physical damage attributable to the observed objects.

Summary -- PART I

This report will consider mainly the reports of Groups 1 and 2.

PART II -- ON POSSIBLE EXPLANATIONS OF THE REPORTS

Section A -- What can be deduced concerning the nature of an unknown aerial object from a single sighting?

Here, there are two problems: first, how much can be deduced concerning the nature of the objects from geometrical calculations alone; second, how much more can be deduced if, in addition, it is assumed that the objects obey the laws of nature as we know them.

Concerning the first problem, it can be stated that only ratios of lengths, and rates of change of such ratios, can be accurately determined. Thus, the range and size of such objects cannot be determined; and it is noticeable that reports of size of the ob erved objects are widely at variance. However, angles, such as the angle subtended by the object, can be observed. Likewise there is fair agreement abong several observers that the diameter of the objects of Group 1 is about ten times their thickness. Although velocity cannot be determined, angular velocity can be, and in particular the flutter frequency could, in principle, be determined.

All that can be concluded about the range and size of the objects, from geometrical considerations alone, is: 1) from the fact that estimated sizes vary so widely, the objects were actually either of ifferent sizes, or more likely, that they were far enough from the observers so that binocular vision produced no stereoscopic effect; this only means that they were farther off than about thirty feet; 2) since objects were seen to disappear behind trees, buildings, clouds, etc., they are large enough to be visible at the ranges of those recognizable objects.

Now, it is obviously of prime importance to estimate the size and mass of the observed objects. This may be possible to some extent if it is permissible to assume that they obey the laws of physics. Since the objects have not been observed to produce any physical effects, other than the one case in which a cloud was evaporated along the trajectory, it is not certain that the laws of mechanics, for instance, would be sufficient.

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But suppose that machanical laws alone are sufficient, then the following example is sufficient proof that at least a length could, in principle, be determined: suppose a simple pendulum were observed suspended in the sky; then after observing its frequency of oscillation, we could deduce from the laws of mechanics its precise length.

This suggests that something could be deduced from the observed fluttering motion of some of the objects of Group 1. Assume that we know the angular frequency and angular amplitude of this fluttering motion (they can be measured in principle from a motion picture). Then for purposes of calculation assume the object to be thirty feet in diameter, to be as rigid as a normal aircraft wing of 30-foot span, to be constructed of material of the optimum weight-strength ratio and to be a structure of most efficient design. It is now possible to calculate how heavy the object must be merely to remain rigid under the observed angular motion. Let the calculation be made for a plurality of assumed sizes 1, 2, 4, 8, 16, 32, 64 ---- up to say 200 feet, and let calculated mass be plotted versus assumed size. The non-linear character of the curve should indicate an approximate upper limit to the size of the object.

If, in addition, it is assumed that the flutter is due to aerodynamic forces, it is possible that more precise information could be obtained.

The required angular data can probably be extracted from the witnesses most relaibly by the use of a demonstration model which can be made to oscillate or flutter in a known way.

Summary -- PART II, Section A

Geometrical calculations alone cannot yield the size of objects observed from a single station; such observation together with the assumption that the objects are essentially aircraft, can be used to set reasonable limits of size.

Section B -- The possibility of supporting and propelling a solid object by unusual means.

Since some observers have obviously colored their reports with talk of rays, jets, beams, space-ships, and the like, it is well to examine what possibilities exist along these lines. This is also important in view of the conclusions of PART II, Section A, of this report.

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Method I -- Propulsion and support by means of "rays" or "beams".

By "rays" or "beams" are meant either purely electromagnetic radiation or else radiation which is largely corpuscular like cathode-rays or cosmic-rays or cyclotron-beams.

Now, it is obvious that any device propelled or supported by such means is fundamentally a reaction device. it is fundamental in the theory of such devices that a given amount of energy is most efficiently spent if the momentum thrown back or down is large. This means that a large mass should be given a small acceleration -- a theorem well understood by helicopter designers.

The beams or rays mentioned do the contrary, a small mass is given a very high velocity, consequently enormous powers, greater than the total world's power copacity, would be needed to support even the smallest object by such means.

Method II -- Direct use of Earth's Magnetic Field

One observer (incident 68) noticed a violent motion of a hand-held compass. If we assume from this that the objects produced a magnetic field, comparable with the Earth's field, namely, 0.1 gauss, and that the observer found that the object subtended an angle θ at his position, then the ampere-turns of the required electromagnet is given by:

$$ni = \frac{30R}{\theta^2} \text{ where R is the range of the object.}$$

For instance, if R is one kilometer and the object is 10 meters in diameter, then ni $\neq$ 1 billion ampere-turns.

Now if the object were actually only 10 meters away and were correspondingly smaller; namely, 10 cm in diameter, it would still require 10 million ampere-turns.

These figures are a little in excess of what can be conveniently done on the ground. They make it seem unlikely that the effect was actually observed.

Now, the Earth's magnetic field would react on such a magnet to produce not only a torque but also a force. This force depends not directly on the Earth's field intensity but on its irregularity or gradient. This force is obviously minute since the change in field over a distance of 10 meters (assumed diameter of the object) is scarcely measureable, moreover the gradient is not predictable but changes due to local ore deposits. Thus, even if the effect were large enough to use, it would still be unreliable and unpredictable.

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Method III -- Support of an electrically-charged object by causing it to move transverse to the Earth's magnetic field.

A positively-charged body moving from west to east, or a negatively-charged body moving from east to west will experience an upward force due to the Earth's magnetic field.

A sphere 10 meters diameter moving at a speed of one kilometer/second would experience an upward force of one pound at the equator if charged to a potential of 5×10^{12} volts. This is obviously ridiculous.

Section D -- The anti-gravity shield

It has been proposed, by various writers, perhaps first by H.G.Wells, that it might be possible to construct a means of shielding a massive body from the influence of gravity. Such an object would then float. Recently, there appeared in the press a notice that a prominent economist has offered to support research on such an enterprise.

Obviously, conservation of energy demands that considerable energy be given the supported object in order to place it on the shield. However, this amount of energy is in no way prohibitive, and furthermore it can be gotten back when the object lands.

Aside from the fact that we have no suggestions as to how such a device is to be made, the various theories of general relativity all agree in assuming that gravitational force and force due to acceleration are indistinguishable, and from this assumption the theories predict certain effects which are in fact observed. The assumption, therefore, is probably correct, and a corollary of it is essentially that only by means of an acceleration can gravity be counteracted. This, we can successfully do for instance by making an artificial satellite, but this presumably is not what has been observed.

Summary -- PART II, Section B

Several unorthodox means of supporting or propelling a solid object have been considered, all are impracticable. This finding lends credence to the tentative proposed assumption of Part II, that the objects are supported and propelled by some normal means, or else that they are not solids. No discussion of the type of Part II, Section B, can, in principle, of course, be complete.

Section C -- Possible causes for the reports

Classification I -- Natural terrestrial phenomena

1. The observations may be due to some effect such as ball of

lightning. The writer has no suggestions on this essentially meteorological subject.

2. The objects may be some kind of animal.

Even in the celebrated case of incident 172 where the light was chased by a P51 for half an hour and which was reported by the pilot to be intelligently directed, we can make this remark. For considering that an intelligence capable of making so remarkable device would not be likely to play around in so idle a manner as described by the pilot.

In this connection, it would be well to examine if some of the lights observed at night were not fire-flies.

3. The observed objects may be hallucinatory or psychological in origin. It is of prime importance to study this possibility because we can learn from it something of the character of the population; its response under attack; and also something about the reliability of visual observation.

One would like to assume that the positions held by many of the reported observers guarantee their observations. Unfortunately, there were many reports of curious phenomena by pilots during the war -- the incident of the fire-ball fighters comes to mind. Further, mariners have been reporting sea-serpents for hundreds of years yet no one has yet produced a photograph.

It would be interesting to tabulate the responses to see how reliable were the reports on the Japanese balloons during the war. There we had a phenomenon proven to be real.

It is interesting that the reports swiftly reach a maximum frequency during the end of June 1947 and then slowly taper off. We can assume that this is actually an indication of how many objects were actually about, or, quite differently, we can take this frequency curve as indicating something about mass psychology.

This point can be tested. Suppose the population is momentarily excited; how does the frequency of reports vary with time? A study of crank letters received after the recent publicity given to the satellite program should give the required frequency distribution.

It is probably necessary but certainly not sufficient that the unidentified-object curve and the crank-letter curve should be similar in order for the flying disks to be classes as hallucinations.

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A large-scale experiment was made at the time of the Orson Welles' "Martian" broadcast. Some records of this must persist in newspaper files.

Classification II -- Man-made terrestrial phenomena

1. The objects may be Russian aircraft. If this were so, then the considerations of Sections A and B indicate that we would have plenty to worry about. It is the author's opinion that only an accidental discovery of a degree of novelty never before achieved could suffice to explain such devices. It is doubtful whether a potential enemy would arouse our curiosity in so idle a fashion.

Classification III -- Extra terrestrial objects.

1. Meteors: It is noteworthy that the British physicist Lovell writing in "Physics Today" mentions the radar discovery of a new day-time meteorite stream which reached its maximum during June 1947. The reported objects lose little of their interest, however, if they are of meteoritic origin.

2. Animals: Although the objects are descirbed act more like animals than anything else, there are few reliable reports on extra-terrestrial animals.

3. Space Ships: The following considerations pertain:

a. If there is an extra terrestrial civilization which can make such objects as are reported then it is most probable that its development is far in advance of ours. This argument can be supported on probability arguments alone without recourse to astronomical hypotheses.

b. Such a civilization might observe that on Earth we now have atomic bombs and are fast developing rockets. In view of the past history of mankind, they should be alarmed. We should, therefore, expect at this time above all to behold such visitations.

Since the acts of mankind most easily observed from a distance are A-bomb explosions we should expect some relation to obtain between the time of A-bomb explosions, the time at which the space ships are seen, and the time required for such ships to arrive from and return to home-base.

PART III -- RECOMMENDATIONS

1. The file should be continued.

2. A meteorologist should compute the approximate energy required

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to evaporate as much cloud as shown in the incident 26 photographs. Together with an aerodynamicist he should examine whether a meteorite of unusual shape could move as observed.

3. The calculations suggested in Part II, Section A, should be estimated by an aerodynamicist with such changes as his more detailed knowledge may suggest.

4. The mass-psychology studies outlined in Part II, Section C, Classification I 3 should be carried out by a competent staff of statisticians and mass-psychologists.

5. Interviewing agents should carry objects or moving pictures for comparison with reporter's memories. These devices should be properly designed by a psychologist experienced in problems pertaining to aircraft and design of aircraft-control equipment so that he shall have some grasp of what it is that is to be found out. If the Air Force has reason to be seriously interested in these reports, it should take immediate steps to interrogate the reporters more precisely.

6. A person skilled in the optics of the eye and of the atmosphere should investigate the particular point that several reports agree in describing the objects as being about ten times as wide as they are thick; the point being to see if there is a plurality of actual shapes which appear so, under conditions approaching limiting resolution or detectable contrast.

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APPENDIX U: REPORT OF MEETINGS OF SCIENTIFIC ADVISORY PANEL
ON UNIDENTIFIED FLYING OBJECTS (ROBERTSON PANEL)
14-18 JANUARY 1953

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INDEX

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16 February 1953

MEMORANDUM FOR:

FROM :

SUBJECT : Report of Meetings of the Scientific Advisory Panel on Unidentified Flying Objects, January 14 - 18, 1953

PURPOSE

The purpose of this memorandum is to present:

a. A brief history of the meetings of the Advisory Panel On Unidentified Flying Objects (Part I),

b. An unofficial supplement to the official Panel Report setting forth comments and suggestions of the Panel Members which they believed were inappropriate for inclusion in the formal report (Part II).

PART I: HISTORY OF MEETINGS

GENERAL

After consideration of the subject of "unidentified flying objects" at the 4 December meeting of the the following action was agreed:

"The will:

a. Enlist the services of selected scientists to review and appraise the available evidence in the light of pertinent scientific theories...."

Following the delegation of this action to the and preliminary investigation,

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an Advisory Panel of selected scientists was assembled. In cooperation with the Air Technical Intelligence Center, case histories of reported sightings and related material were made available for their study and consideration.

Present at the initial meeting (0930 Wednesday, 14 January) were: Dr. H. P. Robertson, Dr. , Dr. Thornton Page, Dr. Samuel A. Goudsmit,

and the writor. Panel Member, Dr. Lloyd V. Berkner, was absent until Friday afternoon. Messrs.

were present throughout the sessions to familiarize themselves with the subject, represent the substantive interest of their Divisions, and assist in administrative support of the meetings. (A list of personnel concerned with the meetings is given in Tab A.

WEDNESDAY MORNING

The opened the meeting, reviewing CIA interest in the subject and action taken. This review included the mention of the Study Group of August 1952 culminating in the briefing of the the ATIC November 21 briefing, 4 December consideration, visit to ATIC Robertson and , and concern over potential dangers to national security indirectly related to these sightings. Mr. enumerated these potential dangers. Following this introduction, Dr. turned the meeting over to

Dr. Robertson as Chairman of the Panel. Dr. Robertson enumerated the evidence available and requested consideration of specific reports and letters be taken by certain individuals present (Tab B). For example, case histories involving radar or radar and visual sightings were selected for Dr.   while reports of Green Fireball phenomena, nocturnal lights, and suggested programs of investigation were routed to Dr. Page. Following these remarks, the motion pictures of the sightings at Tremonton, Utah (2 July 1952) and Great Falls, Montana (15 August 1950) were shown. The meeting adjourned at 1200.

WEDNESDAY AFTERNOON

The second meeting of the Panel opened at 1400. Lt.____ ____ USN, and Mr.__________of the USN Photo Interpretation Laboratory, Anacostia, presented the results of their analyses of the films mentioned above. This analysis evoked considerable discussion as elaborated upon below. Besides Panel members and CIA personnel, Capt. E. J. Ruppelt, Dr.   (2-a-2), and Dr.   were present.

Following the Photo Interpretation Lab presentation, Mr. E. J. Ruppelt spoke for about 40 minutes on ATIC methods of handling and evaluating reports of sightings and their efforts to improve the quality of reports. The meeting was adjourned at 1715.

THURSDAY MORNING

The third and fourth meetings of the Panel were held Thursday, 15 January, commencing at 0900 with a two-hour break for luncheon. Besides Panel members and CIA personnel, Mr. Ruppelt and Dr. ______ were present for both sessions. In the morning, Mr. Ruppelt continued his briefing on ATIC collection and analysis procedures. The Project STORK support at ______________________________ was described by Dr. ______ A number of case histories were discussed in detail and a motion picture film of seagulls was shown. A two hour break for lunch was taken at 1200.

THURSDAY AFTERNOON

At 1400 hours ____________ gave a 40-minute briefing of Project TWINKLE, the investigatory project conducted by the Air Force Meteorological Research Center at Cambridge, Mass. In this briefing he pointed out the many problems of setting up and manning 24-hour instrumentation watches of patrol cameras searching for sightings of U.F.O.'s.

At 1615 __________________________ joined the meeting with ______________________ expressed his support of the Panel's efforts and stated three personal opinions:

a. That greater use of Air Force intelligence officers in the field (for follow-up investigation) appeared desirable. but that they required thorough briefing.

b. That vigorous effort should be made to declassify as many of the reports as possible.

c. That some increase in the ATIC section devoted to U.F.O. analysis was indicated.

This meeting was adjourned at 1700.

FRIDAY MORNING

The fifth session of the Panel convened at 0900 with the same personnel present as enumerated for Thursday (with the exception of ____________.

From 0900 - 1000 there was general discussion and study of reference material. Also, ________ read a prepared paper making certain observations and conclusions. At 1000 ______ gave a briefing on his fifteen months experience in Washington as Project Officer for U.F.O.'s and his personal conclusions. There was considerable discussion of individual case histories of sightings to which he referred. Following ______ presentation, a number of additional case histories were examined and discussed with Messrs. ______ Ruppelt, and ______ The meeting adjourned at 1200 for luncheon.

FRIDAY AFTERNOON

This session opened at 1400. Besides Panel members and CIA personnel, Dr.______ was present. Dr. Lloyd V. Berkner, as Panel Member, was present at this meeting for the first time. Progress of the meetings was reviewed by the Panel Chairman and tentative

conclusions reached. A general discussion followed and tentative recommendations considered. It was agreed that the Chairman should draft a report of the Panel to that evening for review by the Panel the next morning. The meeting adjourned at 1715.

SATURDAY MORNING

At 0945 the Chairman opened the seventh session and submitted a rough draft of the Panel Report to the members. This draft had been reviewed and approved earlier by Dr. Berkner. The next two and one-half hours were consumed in discussion and revision of the draft. At 1100 the joined the meeting and reported that he had shown and discussed a copy of the initial rough draft to the Director of Intelligence, USAF, whose reaction was favorable. At 1200 the meeting was adjourned.

SATURDAY AFTERNOON

At 1400 the eighth and final meeting of the Panel was opened. Discussion and rewording of certain sentences of the Report occupied the first hours. (A copy of the final report is appended as Tab C.) This was followed by a review of work accomplished by the Panel and restatement of individual Panel Member's opinions and suggestions on details that were felt inappropriate for inclusion in the formal report. It was agreed that the writer would incorporate these comments in an internal report to the The material below represents this information.

PART II: COMMENTS AND SUGGESTIONS OF PANEL

GENERAL

The Panel Members were impressed (as have been others, including personnel) in the lack of sound data in the great majority of case histories; also, in the lack of speedy follow-up due primarily to the modest size and limited facilities of the ATIC section concerned. Among the case histories of significant sightings discussed in detail were the following:

Bellefontaine, Ohio (1 August 1952); Tremonton, Utah (2 July 1952); Great Falls, Montana (15 August 1950); Yaak, Montana (1 September 1952); Washington, D. C. area (19 July 1952); and Haneda A.F.B., Japan (5 August 1952), Port Huron, Michigan (29 July 1952); and Presque Isle, Maine (10 October 1952).

After review and discussion of these cases (and about 15 others, in less detail), the Panel concluded that reasonable explanations could be suggested for most sightings and "by deduction and scientific method it could be induced (given additional data) that other cases might be explained in a similar manner". The Panel pointed out that because of the brevity of some sightings (e.g. 2-3 seconds) and the inability of the witnesses to express themselves clearly (semantics) that conclusive explanations could not be expected for every case reported. Furthermore, it was considered that, normally, it would be a great waste of effort to try to solve most of the sightings, unless such action would benefit a training and educational program (see below). The writings of Charles Fort were referenced to show

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that "strange things in the sky" had been recorded for hundreds of years. It appeared obvious that there was no single explanation for a majority of the things seen. The presence of radar and astronomical specialists on the Panel proved of value at once in their confident recognition of phenomena related to their fields. It was apparent that specialists in such additional fields as psychology, meteorology, aerodynamics, ornithology and military air operations would extend the ability of the Panel to recognize many more categories of little-known phenomena.

ON LACK OF DANGER

The Panel concluded unanimously that there was no evidence of a direct threat to national security in the objects sighted. Instances of "Foo Fighters" were cited. These were unexplained phenomena sighted by aircraft pilots during World War II in both European and Far East theaters of operation wherein "balls of light" would fly near or with the aircraft and maneuver rapidly. They were believed to be electrostatic (similar to St. Elmo's fire) or electromagnetic phenomena or possibly light reflections from ice crystals in the air, but their exact cause or nature was never defined. Both Robertson and   had been concerned in the investigation of these phenomena, but David T. Griggs (Professor of Geophysics at the University of California at Los Angeles) is believed to have been the most knowledgeable person on this subject. If the term "flying saucers" had been popular in 1943 - 1945, these objects would

have been so labeled. It was interesting that in at least two cases reviewed that the object sighted was categorized by Robertson and as probably "Foo Fighters", to date unexplained but not dangerous; they were not happy thus to dismiss the sightings by calling them names. It was their feeling that these phenomena are not beyond the domain of present knowledge of physical sciences, however.

AIR FORCE REPORTING SYSTEM

It was the Panel's opinion that some of the Air Force concern over U.F.O.'s (notwithstanding Air Defense Command anxiety over fast radar tracks) was probably caused by public pressure. The result today is that the Air Force has instituted a fine channel for receiving reports of nearly anything anyone sees in the sky and fails to understand. This has been particularly encouraged in popular articles on this and other subjects, such as space travel and science fiction. The result is the mass receipt of low-grade reports which tend to overload channels of communication with material quite irrelevant to hostile objects that might some day appear. The Panel agreed generally that this mass of poor-quality reports containing little, if any, scientific data was of no value. Quite the opposite, it was possibly dangerous in having a military service foster public concern in "nocturnal meandering lights". The implication being, since the interested agency was military, that these objects were or might be potential direct threats to national security. Accordingly, the need for deemphasization made itself apparent. Comments on a possible educational program are enumerated below.

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It was the opinion of Dr. Robertson that the "saucer" problem had been found to be different in nature from the detection and investigation of German V-1 and V-2 guided missiles prior to their operational use in World War II. In this 1943-1944 intelligence operation (CROSSBOW), there was excellent intelligence and by June 1944 there was material evidence of the existence of "hardware" obtained from crashed vehicles in Sweden. This evidence gave the investigating team a basis upon which to operate. The absence of any "hardware" resulting from unexplained U.F.O. sightings lends a "will-of-the wisp" nature to the ATIC problem. The results of their investigation, to date, strongly indicate that no evidence of hostile act or danger exists. Furthermore, the current reporting system would have little value in the case of detection of enemy attack by conventional aircraft or guided missiles; under such conditions "hardware" would be available almost at once.

ARTIFACTS OF EXTRATERRESTRIAL ORIGIN

It was interesting to note that none of the members of the Panel were loath to accept that this earth might be visited by extra-terrestrial intelligent beings of some sort, some day. What they did not find was any evidence that related the objects sighted to space travelers. Mr. in his presentation, showed how he had eliminated each of the known and probable causes of sightings leaving him "extra-terrestrial" as the only one remaining in many cases. 's background as an aeronautical engineer and technical intelligence

officer (Project Officer, BLUEBOOK for 15 months) could not be slighted. However, the Panel could not accept any of the cases cited by him because they were raw, unevaluated reports. Terrestrial explanations of the sightings were suggested in some cases and in others the time of sighting was so short as to cause suspicion of visual impressions. It was noted by Dr. Goudsmit and others that extraterrestrial artifacts, if they did exist, are no cause for alarm; rather, they are in the realm of natural phenomena subject to scientific study, just as cosmic rays were at the time of their discovery 20 to 30 years ago. This was an attitude in which Dr. Robertson did not concur, as he felt that such artifacts would be of immediate and great concern not only to the U. S. but to all countries. (Nothing like a common threat to unite peoples!) Dr. Page noted that present astronomical knowledge of the solar system makes the existence of intelligent beings (as we know the term) elsewhere than on the earth extremely unlikely, and the concentration of their attention by any controllable means confined to any one continent of the earth quite preposterous.

TREMONTON, UTAH, SIGHTING

This case was considered significant because of the excellent documentary evidence in the form of Kodachrome motion picture films (about 1600 frames). The Panel studied these films, the case history, ATIC's interpretation, and received a briefing by representatives of the USN Photo Interpretation Laboratory on their analysis of the film. This team had expended (at Air Force request) approximately

1000 man-hours of professional and sub-professional time in the preparation of graph plots of individual frames of the film, showing apparent and relative motion of objects and variation in their light intensity. It was the opinion of the P.I.L. representatives that the objects sighted were not birds, balloons or aircraft, were "not reflections because there was no blinking while passing through 60° of arc" and were, therefore, "self-luminous". Plots of motion and variation in light intensity of the objects were displayed. While the Panel Members were impressed by the evident enthusiasm, industry and extent of effort of the P.I.L. team, they could not accept the conclusions reached. Some of the reasons for this were as follows:

a. A semi-spherical object can readily produce a reflection of sunlight without "blinking" through 60° of arc travel.

b. Although no data was available on the "albedo" of birds or polyethylene balloons in bright sunlight, the apparent motions, sizes and brightnesses of the objects were considered strongly to suggest birds, particularly after the Panel viewed a short film showing high reflectivity of seagulls in bright sunlight.

c. P.I.L. description of the objects sighted as "circular, bluish-white" in color would be expected in cases of specular reflections of sunlight from convex surfaces where the brilliance of the reflection would obscure other portions of the object.

d. Objects in the Great Falls case were believed to have probably been aircraft, and the bright lights such reflections.

e. There was no valid reason for the attempt to relate the objects in the Tremonton sighting to those in the Great Falls sighting. This may have been due to misunderstanding in their directive. The objects in the Great Falls sighting are strongly suspected of being reflections of aircraft known to have been in the area.

f. The intensity change in the Tremonton lights was too great for acceptance of the P.I.L. hypothesis that the apparent motion and changing intensity of the lights indicated extremely high speed in small orbital paths.

g. Apparent lack of guidance of investigators by those familiar with U.F.O. reports and explanations.

h. Analysis of light intensity of objects made from duplicate rather than original film. The original film was noted to have a much lighter background (affecting relative brightness of object) and the objects appeared much less bright.

i. Method of obtaining data of light intensity appeared faulty because of unsuitability of equipment and questionable assumptions in making averages of readings.

j. No data had been obtained on the sensitivity of Kodachrome film to light of various intensities using the same camera type at the same lens openings.

k. Hand "jitter" frequencies (obtainable from early part of Tremonton film) were not removed from the plots of the "single pass plots" at the end of the film.

The Panel believed strongly that the data available on this sighting was sufficient for positive identification if further data is obtained by photographing polyethylene "pillow" balloons released near the site under similar weather conditions, checking bird flight and reflection characteristics with competent ornithologists and calculating apparent "G" forces acting upon objects from their apparent tracks. It was concluded that the results of such tests would probably lead to creditable explanations of value in an educational or training program. However, the Panel noted that the cost in technical manpower effort required to follow up and explain every one of the thousand or more reports received through channels each year (1,900 in 1952) could not be justified. It was felt that there will always be sightings, for which complete data is lacking, that can only be explained with disproportionate effort and with a long time delay, if at all. The long delay in explaining a sighting tends to eliminate any intelligence value. The educational or training program should have as a major purpose the elimination of popular feeling that every sighting, no matter how poor the data, must be explained in detail. Attention should be directed to the requirement among scientists that a new phenomena, to be accepted, must be completely and convincingly documented. In other words, the burden of proof is on the sighter, not the explainer.

POTENTIAL RELATED DANGERS

The Panel Members were in agreement with opinion that, although evidence of any direct threat from these sightings was wholly lacking, related dangers might well exist resulting from:

a. Misidentification of actual enemy artifacts by defense personnel.

b. Overloading of emergency reporting channels with "false" information ("noise to signal ratio" analogy - Berkner).

c. Subjectivity of public to mass hysteria and greater vulnerability to possible enemy psychological warfare.

Although not the concern of CIA, the first two of these problems may seriously affect the Air Defense intelligence system, and should be studied by experts, possibly under ADC. If U.F.O.'s become discredited in a reaction to the "flying saucer" scare, or if reporting channels are saturated with false and poorly documented reports, our capability of detecting hostile activity will be reduced. Dr. Page noted that more competent screening or filtering of reported sightings at or near the source is required, and that this can best be accomplished by an educational program.

GEOGRAPHIC LOCATIONS OF UNEXPLAINED SIGHTINGS

The map prepared by ATIC showing geographic locations of officially reported unexplained sightings (1952 only) was examined by the Panel. This map showed clusters in certain strategic areas such as Los Alamos. This might be explained on the basis of 24-hour watchful guard and

awareness of security measures near such locations. On the other hand, there had been no sightings in the vicinity of sensitive related AE establishments while there were occasionally multiple cases of unexplained sightings in non-strategic areas. Furthermore, there appeared to be no logical relationship to population centers. The Panel could find no ready explanation for these clusters. It was noted, however, that if terrestrial artifacts were to be observed it would be likely that they would be seen first near foreign areas rather than central U. S.

INSTRUMENTATION TO OBTAIN DATA

The Panel was of the opinion that the present ATIC program to place 100 inexpensive 35 mm. stereo cameras in the hands of various airport control tower operators would probably produce little valuable data related to U.F.O.'s. However, it was recognized that such action would tend to allay public concern in the subject until an educational program had taken effect. It was believed that procurement of these cameras was partly the result of public pressure in July 1952. With the poor results of the year-long Project TWINKLE program of 24-hours instrumentation watch (two frames of film showing nothing distinguishable), a widespread program of sky-watching would not be expected to yield much direct data of value.

There was considerable discussion of a possible "sky patrol" by amateur astronomers and by wide-angle cameras (Page). Dr. Page and Dr. Robertson pointed out that at present a considerable fraction

of the sky is now--and has been for many years-under surveillance every clear night in several meteor and aurora observing programs as well as sky mapping programs at the various locations listed below. Although the attention of these astronomers is largely directed toward identified rather than unidentified objects, no case of any striking unidentified object is known to Dr. Page or Dr. ____ Such an object would most certainly be reported if found on patrol plates.

A case was cited where an astronomer refused to interrupt his exposure in order to photograph an alleged sighting in a different part of the sky. This led Dr. ____ to say that, if a program of watching could be an adjunct of planned astronomical programs, little cost would be involved and that the trained astronomical personnel might photograph a sighting of an unidentified object.

The location of some of these programs and their directors are believed to be:

a. Harvard University, Cambridge and New Mexico (meteor patrol)--Whipple.

b. Yerkes Observatory, University of Chicago and Fort Davis, Texas (several programs)--Meinel (auroras), Kuiper (asteroids), Morgan (wide angle camera).

c. University of Alaska, Fairbanks (aurorae)--Elvey

d. Dominion Observatory, Ottawa (meteors)--Millman

e. Palomar Observatory, California (sky map)--Minkowski

f. Lick Observatory, California (sky map)--Shane

It was agreed by the Panel that no government-sponsored program of optical nation-wide sky patrol is worthwhile at the present time, and that the encouragement of amateur astronomers to undertake such a program might have the adverse effect of over-emphasizing "flying saucer" stories in the public mind. However, the issue of radar scope cameras for recording peculiar radar echoes would serve several purposes, including the better understanding of radar interference as well as identification of U.F.O.'s.

RADAR PROBLEM OF MUTUAL INTERFERENCE

This characteristic problem of radar operation wherein the pulse signal (of approximately the same frequency) from station A may be picked up on the screen of station B and show as a high-speed track or series of dots was recognized to have probably caused a number of U.F.O. reports. This problem was underlined by information received indicating ADC concern in solving this problem of signal identification before service use of very high-speed aircraft or guided missiles (1955-1956). Dr. Berkner believed that one answer to this problem was the use of a "doppler filter" in the receiving circuit. Dr. ______ suggested that the problem might be better solved by the use of a "controlled jitter" wherein the operator receiving "very fast tracks" (on the order of 1000- 10,000 m.p.h.) would operate a circuit which would alter slightly his station's pulse frequency rate. If the signal received on the screen had been caused by mutual interference with another station, the track would now show itself at a different distance

from the center of the screen, if it still appeared at all. Dr. _____ felt such a technical solution was simpler and would cost much less than a "doppler filter".

UNEXPLAINED COSMIC RAY PHENOMENA

Two reported cases were examined: one at Palomar Mountain, California, in October 1949, when cosmic ray counters went "off scale for a few seconds", apparently while a "V" of flying saucers was observed visually; and two, a series of observations by the "Los Alamos Bird Watchers Association" from August 1950 to January 1951, when cosmic ray coincidence counters behaved queerly. Circuit diagrams and records were available for the latter, and Dr. _______ was able quickly to point out that the recorded data were undoubtedly due to instrumental effects that would have been recognized as such by more experienced observers.

The implication that radioactive effects were correlated with unidentified flying objects in these two cases was, therefore, rejected by the Panel.

EDUCATIONAL PROGRAM

The Panel's concept of a broad educational program integrating efforts of all concerned agencies was that it should have two major aims: training and "debunking".

The training aim would result in proper recognition of unusually illuminated objects (e.g., balloons, aircraft reflections) as well as natural phenomena (meteors, fireballs, mirages, noctilucent clouds). Both visual and radar recognition are concerned. There would be many

levels in such education from enlisted personnel to command and research personnel. Relative emphasis and degree of explanation of different programs would correspond to the categories of duty (e.g., radar operators; pilots; control tower operators; Ground Observer Corps personnel; and officers and enlisted men in other categories.) This training should result in a marked reduction in reports caused by misidentification and resultant confusion.

The "debunking" aim would result in reduction in public interest in "flying saucers" which today evokes a strong psychological reaction. This education could be accomplished by mass media such as television, motion pictures, and popular articles. Basis of such education would be actual case histories which had been puzzling at first but later explained. As in the case of conjuring tricks, there is much less stimulation if the "secret" is known. Such a program should tend to reduce the current gullibility of the public and consequently their susceptibility to clever hostile propaganda. The Panel noted that the general absence of Russian propaganda based on a subject with so many obvious possibilities for exploitation might indicate a possible Russian official policy.

Members of the Panel had various suggestions related to the planning of such an educational program. It was felt strongly that psychologists familiar with mass psychology should advise on the nature and extent of the program. In this connection, Dr. Hadley Cantril (Princeton University) was suggested. Cantril authored "Invasion from

Mars," (a study in the psychology of panic, written about the famous Orson Welles radio broadcast in 1938) and has since performed advanced laboratory studies in the field of perception. The names of Don Marquis (University of Michigan) and Leo Roston were mentioned as possibly suitable as consultant psychologists. Also, someone familiar with mass communications techniques, perhaps an advertising expert, would be helpful. Arthur Godfrey was mentioned as possibly a valuable channel of communication reaching a mass audience of certain levels. Dr. Berkner suggested the U. S. Navy (ONR) Special Devices Center, Sands Point, L. I., as a potentially valuable organization to assist in such an educational program. The teaching techniques used by this agency for aircraft identification during the past war was cited as an example of a similar educational task. The Jam Handy Co. which made World War II training films (motion picture and slide strips) was also suggested, as well as Walt Disney, Inc. animated cartoons. Dr. ___ suggested that the amateur astronomers in the U. S. might be a potential source of enthusiastic talent "to spread the gospel". It was believed that business clubs, high schools, colleges, and television stations would all be pleased to cooperate in the showing of documentary type motion pictures if prepared in an interesting manner. The use of true cases showing first the "mystery" and then the "explanation" would be forceful.

To plan and execute such a program, the Panel believed was no mean task. The current investigatory group at ATIC would, of necessity, have to be closely integrated for support with respect to not only the

historical cases but the current ones. Recent cases are probably much more susceptible to explanation than older ones; first, because of ATIC's experience and, secondly, their knowledge of most plausible explanations. The Panel believed that some expansion of the ATIC effort would certainly be required to support such a program. It was believed inappropriate to state exactly how large a Table of Organization would be required. Captain Ruppelt of ATIC unofficially proposed, for purposes of analyzing and evaluating reports:

a. An analysts' panel of four officers

b. Four officer investigators

c. A briefing officer

d. An ADC liaison officer

e. A weather and balloon data officer

f. An astronomical consultant

g. A group Leader, with administrative assistant, file clerks and stenographers.

This proposal met with generally favorable comment. The Panel believed that, with ATIC's support, the educational program of "training and debunking" outlined above might be required for a minimum of one and one-half to two years. At the end of this time, the dangers related to "flying saucers" should have been greatly reduced if not eliminated. Cooperation from other military services and agencies concerned (e.g., Federal Civil Defense Administration) would be a necessity. In investigating significant cases (such as the Tremonton, Utah, sighting), controlled experiments might be required. An example

would be the photographing of "pillow balloons" at different distances under similar weather conditions at the site.

The help of one or two psychologists and writers and a subcontractor to produce training films would be necessary in addition. The Panel considered that ATIC's efforts, temporarily expanded as necessary, could be most useful in implementing any action taken as a result of its recommendations. Experience and records in ATIC would be of value in both the public educational and service training program envisaged. Dr. Robertson at least was of the opinion that after public gullibility lessened and the service organizations, such as ADC, had been trained to sift out the more readily explained spurious sightings, there would still be a role for a very modest-sized ATIC section to cope with the residuum of items of possible scientific intelligence value. This section should concentrate on energetically following up (perhaps on the advice of qualified Air Force Scientific Advisory Board members) those cases which seemed to indicate the evidence of unconventional enemy artifacts. Reports of such artifacts would be expected to arise mainly from Western outposts in far closer proximity to the Iron Curtain than Lubbock, Texas!

UNOFFICIAL INVESTIGATING GROUPS

The Panel took cognizance of the existence of such groups as the "Civilian Flying Saucer Investigators" (Los Angeles) and the "Aerial Phenomena Research Organization (Wisconsin)". It was believed that such organizations should be watched because of their potentially

great influence on mass thinking if widespread sightings should occur. The apparent irresponsibility and the possible use of such groups for subversive purposes should be kept in mind.

INCREASE IN NUMBER OF SIGHTINGS

The consensus of the Panel was, based upon the history of the subject, that the number of sightings could be reasonably expected to increase again this summer.

TAB A

REPORT OF THE SCIENTIFIC PANEL
ON
UNIDENTIFIED FLYING OBJECTS

1. Pursuant to the request [redacted], the undersigned Panel of Scientific Consultants has met to evaluate any possible threat to national security posed by Unidentified Flying Objects ("Flying Saucers"), and to make recommendations thereon. The Panel has received the evidence as presented by cognizant intelligence agencies, primarily the Air Technical Intelligence Center, and has reviewed a selection of the best documented incidents.

2. As a result of its considerations, the Panel <u>concludes</u>:

a. That the evidence presented on Unidentified Flying Objects shows no indication that these phenomena constitute a direct physical threat to national security.

We firmly believe that there is no residuum of cases which indicates phenomena which are attributable to foreign artifacts capable of hostile acts, and that there is no evidence that the phenomena indicates a need for the revision of current scientific concepts.

3. The Panel further <u>concludes</u>:

a. That the continued emphasis on the reporting of these phenomena does, in these parlous times, result in a threat to the orderly functioning of the protective organs of the body politic.

We cite as examples the clogging of channels of communication by irrelevant reports, the danger of being led by continued false alarms to ignore real

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indications of hostile action, and the cultivation of a morbid national psychology in which skillful hostile propaganda could induce hysterical behavior and harmful distrust of duly constituted authority.

4. In order most effectively to strengthen the national facilities for the timely recognition and the appropriate handling of true indications of hostile action, and to minimize the concomitent dangers alluded to above, the Panel <u>recommends</u>:

a. That the national security agencies take immediate steps to strip the Unidentified Flying Objects of the special status they have been given and the aura of mystery they have unfortunately acquired;

b. That the national security agencies institute policies on intelligence, training, and public education designed to prepare the material defenses and the morale of the country to recognize most promptly and to react most effectively to true indications of hostile intent or action.

We suggest that these aims may be achieved by an integrated program designed to reassure the public of the total lack of evidence of inimical forces behind the phenomena, to train personnel to recognize and reject false indications quickly and effectively, and to strengthen regular channels for the evaluation of and prompt reaction to true indications of hostile measures.

/s/ H. P. Robertson, Chairman
California Institute of Technology

/s/ Luis W. Alvarez
University of California

/s/ Lloyd V. Berkner
Associated Universities, Inc.

/s/ S. A. Goudsmit
Brookhaven National Laboratories

/s/ Thornton Page
Johns Hopkins University

UNCLASSIFIED

TAB B

SCIENTIFIC ADVISORY PANEL ON

UNIDENTIFIED FLYING OBJECTS

14 - 17 January 1953

EVIDENCE PRESENTED

1. Seventy-five case histories of sightings 1951 - 1952 (selected by ATIC as those best documented).

2. ATIC Status and Progress Reports of Project GRUDGE and Project BLUE BOOK (code names for ATIC study of subject).

3. Progress Reports of Project STORK ____ ______________________ ______ (contract work supporting ATIC).

4. Summary Report of Sightings at Holloman Air Force Base, New Mexico.

5. Report of USAF Research Center, Cambridge, Mass., Investigation of "Green Fireball" Phenomena (Project TWINKLE).

6. Outline of Investigation of U.F.O.'s Proposed by Kirtland Air Force Base (Project POUNCE).

7. Motion Picture Films of sightings at Tremonton, Utah, 2 July 1952 and Great Falls, Montana, August 1950.

8. Summary Report of 89 selected cases of sightings of various categories (Formations, Blinking Lights, Hovering, etc.).

9. Draft of manual: "How to Make a FLYOBRPT", prepared at ATIC.

10. Chart Showing Plot of Geographic Location of Unexplained Sightings in the United States during 1952.

11. Chart Showing Balloon Launching Sites in the United States.

12. Charts Showing Selected Actual Balloon Flight Paths and Relation to Reported Sightings.

13. Charts Showing Frequency of Reports of Sightings, 1948 - 1952.

14. Charts Showing Categories of Explanations of Sightings.

15. Kodachrome Transparencies of Polyethylene Film Balloons in Bright Sunlight Showing High Reflectivity.

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16. Motion picture of seagulls in bright sunlight showing high reflectivity.

17. Intelligence Reports Relating to U.S.S.R. Interest in U. S. Sightings.

18. Samples of Official USAF Reporting Forms and Copies of Pertinent Air Force, Army and Navy Orders Relating to Subject.

19. Sample Polyethylene "Pillow" Balloon (54 inches square).

20. "Variations in Radar Coverage", JANP 101 (Manual illustrating unusual operating characteristics of Service radar).

21. Miscellaneous official letters and foreign intelligence reports dealing with subject.

22. Copies of popular published works dealing with subject (articles in periodicals, newspaper clippings and books).

SECRET UNCLASSIFIED

"I could more easily believe that two Yankee professors would lie than that stones would fall from heaven." If President Thomas Jefferson could say this so unluckily in 1807, what should we say today to the contention that our earth is visited not merely by stones but by craft manned by intelligent beings? Jefferson's disbelief had in effect already been dealt with by Chladni, famous for his vibrating plates, in a battle with the French Academy that had reached its height about 1790. By that time, as Paneth has said, men of science were far too sophisticated to accept such yarns as that stones should fall out of the sky; but Chladni, who was a lawyer as well as a scientist, believed from his legal experience that eyewitnesses to meteorite falls were genuinely describing a natural phenomenon. After a 10 year battle, he ultimately convinced the French Academy that it was wrong, and that meteorites were real.

Perhaps my one claim to be writing this article is that to some extent I share Chladni's experience, for as an Intelligence Officer I had often to investigate the evidence of witnesses when it conflicted with established 'science', and sometimes it was the 'science' that was wrong. Let me therefore look as dispassionately as possible at the character of the evidence regarding 'flying saucers'. The phrase itself dates from 24 June 1947, but it seems that the apparitions to which it refers had occurred many times before then. Whether or not it was in the heavens that Ezekiel saw his wheels, the sky was a sufficient source of signs for the Roman augurs to scan it in their prognostic routine and it seems to have encouraged the Emperor Constantine handsomely with a χ–ρ celestial monogram before the battle of the Milvian Bridge. In the same tradition, some of us can remember the Angels of Mons.

It may indeed turn out that apparitions have been seen in the sky as long as human records have been kept. In his *History of the English Church and People*, Bede (735) described what would today almost certainly be claimed as flying saucers; and I remember reading an 11th or 12th century account where an object in the sky had caused "multum terrorem" to the brothers in a monastery. And perhaps for almost as long, the tendency of humanity to scare itself has been exploited by the hoaxer. I have read that Newton as a boy of 12 caused much alarm in his Lincolnshire village by flying a kite with a lantern at night.

There was much concern in England in 1882 when as objective an observer as E. W. Maunder of the Royal Observatory saw what he considered to be a celestial visitor. The object was also seen on the Continent by a future Nobel Laureate, the famous spectroscopist Zeeman. It was described in various ways — 'spindle shaped', 'like a torpedo, or weaver's shuttle', 'like a discus seen on edge' and so forth. It was said to glow with a whitish colour. From measurements made on it, it must have been very large — perhaps 70 miles long and situated more than 100 miles above the earth's surface. Although Maunder said that it was different from any auroral phenomenon that he had seen, it is noteworthy that there was an intense magnetic storm at the time, coinciding with one of the largest sunspots ever recorded. It is therefore likely that Maunder's object was an unusual feature of an auroral display. There was another scare in 1897, when something like a winged cigar projecting a brilliant light from its head was seen over Oakland, California (Fort 1941). Similar objects were soon seen throughout the United States, but while some were undoubtedly the work of hoaxers, the cause of the original incident remains obscure.

My own contact with the subject goes back to about 1925, when I was told at Oxted in Surrey of a bright light that slowly made its way across the sky every night. In fact, I knew of one married couple who sat up all night watching it. It was Venus, which had attracted them by its brilliance; they had never before noticed that all the planets and stars seem to move across the sky. Venus, indeed, has caused much trouble through the years. In 1940 or 1941 there was an alarm that the Germans had a new high flying aircraft, because this was what was reported by the predictor crew of an antiaircraft battery somewhere, I think, in the Borders. The aircraft, they said, was showing a light and they had determined its height with their rangefinder. The answer was, as far as I can remember, 26 000 ft and we wondered how they had managed to get such a precise measurement. Investigations showed that this was the last graduation on their range scale and that what they had tried to range upon was, once again, Venus. The same explanation has been true of several flying saucers that have been drawn to my attention in the north of Scotland; it has sometimes been possible to predict the nights on which reports would come in, depending on whether or not Venus was bright and visible.

It is necessary, in any discussion of flying saucers, to consider the nature of the evidence concerning them; it may therefore be relevant if I recount some of my experiences in similar matters, for the tensions associated with war provided fertile ground for the conception of apparitions. I can remember the Russians with the snow on their boots who came to Britain in 1914. One of my uncles was among the hundreds of people who saw them although, in his case, he could not see the snow because they were in a train going over a railway bridge. In fact no detachment of Russian troops ever came to this country. Years later I was told the explanation by the Chief of our Secret Service. In prewar days there used to be large consignments of eggs imported from Russia, and one of the ports at which they were landed was Aberdeen. An agent in Aberdeen on this particular occasion sent a telegram to his London headquarters to warn them that the eggs had been

Based on a lecture given to the North Eastern Branch of the Institute and Society and the Newcastle Astronomical Society.

anded and were on the train. With telegraphic economy he sent a signal such as "100000 Russians now on way from Aberdeen to London" and inadvertently started the legend.

The years before 1939 were full of stories of an engine stopping ray. As I heard the story in 1937 or 1938 it was that an English family on holiday in Germany would be travelling in a car when its engine would suddenly fail, invariably on a country road, and usually at the edge of a wood. A German sentry would then step out of the trees and tell them that there were special tests in progress and that they would be unable to proceed. Some time later he would come back and tell them that it was all right for them to start the engine again and the engine would immediately fire and they were able to drive off.

By this time I was becoming concerned with Intelligence, and one of my tasks was to ascertain the truth about the mysterious rays. At about the same time someone thought that it was a pity that the Germans should have a monopoly in the story and a parallel story was deliberately spread, hinting that we, too, had a ray. Within a short time we in Intelligence were flooded out with stories of similar events in England. We were astonished at the circumstantial detail that the public had added. In one instance, said to have occurred on Salisbury Plain, it was no ordinary family that were in their car, but a family of Quakers — and Quakers, it was added, were well known for telling the truth.

Eventually, I got to the bottom of the story. The places most mentioned in Germany were the regions around the Brocken in the Harz, and the Feldberg near Frankfurt. These were the sites of the first two television towers in Germany. A Jewish radio announcer at Frankfurt who escaped to this country was at first puzzled when I told him the story and then, with a chuckle, he told me that he could see how it had happened. In the days before the television transmitters had been erected, the engineers made field strength surveys, but these surveys were rendered difficult by interference from the engines of motor vehicles. Under an authoritarian regime such as that of the Nazis it was simple to eliminate this trouble by stopping all cars in the area around the survey receiver for the period of the test. Sentries, who were probably provided by the German Air Force, were posted on the roads, and at the appointed hour would emerge and stop all vehicles At the end of the test they would then give the drivers permission to proceed. It only required a simple transposition in the story as subsequently told by a driver for the vehicle to have stopped before the sentry appeared, giving rise to a two year chase after the truth.

The beginning of the second World War took me for a few weeks to Harrogate, where part of the Air Ministry was evacuated. I soon saw a flying saucer. It was high in the blue of a clear midday sky, gleaming white, and appearing hardly to move. Everyone stopped to watch it, but it was merely an escaped balloon. Such objects appeared throughout the war and were even reported by fighter pilots who tried to intercept them, only to find that the objects were too high. There were indeed enough such incidents for part of the Intelligence Organization to suppose that the Germans had developed a special high flying version of the Junkers 86 aircraft known as the Ju 86P, P indicating that the cabin was pressurized (an unusual step in those days) for the crew. It was further supposed that these Ju 86P's were flying photographic reconnaissances of this country and that we were powerless to intercept them. I doubt in fact whether any such reconnaissances were made — certainly, and very surprisingly, there was no photographic reconnaissance of London by the Germans from 10 January 1941 until 10 September 1944 when the Me 262 jet became available.

1940 was a grand time for scares. Many people saw flares fired up by Fifth Columnists to guide the German bombers to their targets; I even had an eyewitness account from an RAF friend who had worked with me in finding the German navigational beams. I was involved in a hunt for Fifth Columnists in Norfolk in which the details were far more convincing than those of any Flying Saucer story that I have encountered but the explanation turned out to be quite innocent. Happily, observations of curious lights were not confined to one side. I was delighted to watch the pilots of Kampfgruppe 100 (the 'crack' beam bombing unit of the German Air Force) conduct a three week test of a theory that our Observer Corps was indicating the presence of German bombers to our fighters by switching on red lights whenever a German bomber was overhead. At the end of the check the Kgr 100 crews reported that they had confirmed the observation, despite the fact that we were doing no such thing.

Air crew, because of the intense strain involved, appeared to be especially susceptible to apparitions. Air Commodore Helmore, one of our ablest pilots in World War I, recalled to me in 1939 that he and his contemporaries had been scared of a particular kind of German antiaircraft shell which burst with a purple flash. The legend was that these shells somehow radiated venereal disease — one can only guess at the chain of events that led up to these speculations.

In World War II our bomber crews repeatedly reported that they were shadowed by German single engine night fighters carrying yellow lights in their noses. The oddness of this observation was that, apart from the difficulty of putting a light in the nose of a single engine aircraft, there were at that time no German single engine fighters flying at night. No one ever completely explained the story. When I did get a chance to ask a German nightfighter crew whether they knew what the explanation was they said that they also knew that no single engine fighters were flying but that they had seen much the same thing as I described to them. American aircraft, later in the war, also saw what may have been the same phenomenon, both over Europe and over Japan. One theory, advanced by Professor Menzel (1953), who has studied such incidents in detail, is that it may have been some effect of light reflected from condensation in wing tip eddies.

Another of the aircrew theories, which ultimately did us very great harm, was that the control of German searchlights was mysteriously put out of action if our bomber switched on its radar identification device. Some of our most experienced and cool headed pilots believed this story, although one could see that it was ridiculous. Even if, by some accident, the German radar control had been upset originally by the radiation from our identification set, the Germans would very clearly have remedied the defect and used the radiation from our set as a means of identifying and locating our bombers — for we had thereby presented them with the answer to one of the most difficult problems in combat, that of getting your enemy positively to identify himself. They indeed exploited this technique towards the end of the war when their main radar equipment was jammed, and it cost us many bombers before we persuaded the Command that it must get the IFF sets switched off. There was another story that a beer bottle thrown out of a bomber would defeat the German radar, and I can remember Lord Cherwell's humorous question "Must it be a freshly opened bottle?"

being solemnly recorded in the minutes of a War Cabinet discussion.

I had often to assess the evidence of eyewitnesses but even when these were observers who were anxious to help us, it was sometimes surprising how much in error their descriptions could be. I received, for example, three reports within a few weeks of one another in 1941 regarding German constructional activity on Mont Pinçon in Normandy. One report said that it was an underground aerodrome, the second that it was a long range gun and the third that it was a radio mast about 1100 ft high. Faced with such diversity, I guessed that none of these descriptions was correct but that, from the site, the construction was probably a radio navigational beam station, with an aerial (which was, incidentally, about 40 ft high) which could be rotated on a turntable of about 100 ft diameter. Photographic reconnaissance showed that my guess was correct; it also illustrated a more general point that witnesses were usually right when they said that something had happened at a particular place, although they could be wildly wrong about what had happened.

Another example that occurred, not to me but to Professor Charles Kittel, the American solid state physicist, may also be salutary. He and a British theoretical physicist were given the problem of establishing the pattern on which the Germans laid their mines at sea, the principal evidence being derived from the reports of minesweeper crews regarding the range and bearing of the mines as they were exploded by the passage of minesweepers. Kittel proposed to go on a minesweeping sortie, to get the feel of the evidence. His British counterpart refused to go, on the grounds that since they would only be making one trip the evidence that they were likely to obtain would be highly special to that particular trip and might colour their general judgement. Kittel at once found out the surprising fact that the reports of the crews were completely unreliable as regards range and bearing estimation, and that the only part of the evidence on which he could rely was whether the explosion had occurred to port or starboard. I believe that he managed to solve the problem of the pattern on this evidence alone, but that his colleague remained perplexed until the end of the war through accepting the ranges and bearings as accurate.

I have made this discursion into some of my war experience because it is relevant to the flying saucer story in that it illustrates the difficulty of establishing the truth from eyewitness reports, particularly when events have been witnessed under stress. I do not, of course, conclude that eyewitness reports must be discarded; on the contrary, excluding hoaxers and liars, most witnesses have genuinely seen something, although it may be difficult to decide from their descriptions what they really had seen.

The end of the war brought me an experience that was directly connected with the flying saucer problem. In fact, although the term was invented in America as the result of something seen by Kenneth Arnold, piloting a private plane near Mt Ranier on 24 June 1947, the modern scare about strange celestial objects started in Sweden early in 1946. I was Director of Intelligence on the Air Staff at the time and I had to decide whether or not there was anything in the story. I am not sure of the incident that started it off, but the general atmosphere was one of apprehension regarding the intentions of the Russians, now that their post-war attitude was becoming clear. It was, for example, the time of Winston Churchill's 'iron curtain' speech. At any rate, a number of stories began about people seeing things in the sky over Sweden, and this gained such volume that the Swedish General Staff asked the population in general to keep its eyes open. The result, of course, was an immediate spate of reports. Many of these could be quickly dismissed by explanations such as wild geese seen at a distance, but one or two were so widely reported that they must have been something more unusual.

Some of the technical officers on my staff were quite convinced and subscribed to the Swedish explanation that the objects were long range flying bombs being sent over Sweden by the Russians. Even such a cool headed judge as Field Marshal Smuts was convinced enough to refer to them in a broadcast talk as evidence of the Russian threat. The belief was strongly aided by what I think must have been two unusually bright meteors, which were clearly visible in daylight. One of these led to many reports almost simultaneously, from a wide area of Sweden; an enthusiastic Intelligence officer joined all the reports up into one track according to the times of the individual reports and this track seemed to show that the object sometimes hovered and sometimes flew for hundreds of miles within half a minute. What he had failed to notice was that almost every report said that the object had been seen to the east of the observer, and this would have been impossible if his track was genuine. The explanation, of course, was that the individual times of sighting that were reported represented the scatter of errors in the individual watches of the observers, and that they had all been witnessing one event; this was a large, bright meteor that had appeared over the Gulf of Finland.

However, such a simple explanation did not satisfy some of my officers, who clearly disapproved of my scepticism. I pointed out to them that since we had two years before studied the behaviour of German flying bombs, we knew the order of reliability of such missiles, which was such that 10% or so would come down accidentally through engine failure. The Russians were supposedly cruising their flying bombs at more than twice the range that the Germans had achieved, and it was unlikely that they were so advanced technologically as to achieve a substantially greater reliability at 200 miles than the Germans had reached at 100 miles. Even, therefore, if they were only trying to frighten the Swedes, they could hardly help it if some of their missiles crashed on Swedish territory. The alleged sightings over Sweden were now so many that even giving the Russian the greatest possible credit for reliability, there ought to be at least 10 missiles already crashed in Sweden. I would therefore only believe the story if someone brought me in a piece of a missile.

I did not have to wait long. The other Director of Intelligence on the Air Staff, an Air Commodore who tended to side with those who believed in the story, telephoned me to say that while the Swedes had not actually picked up a crashed missile, someone had seen objects fall from one of the missiles and had collected them. The Swedish General Staff handed them to us for examination; they were a miscellaneous collection of irregular lumps of material. The piece that I remember best was perhaps three inches across, grey, porous and shiny, and with a density not much more than that of water. Charles Frank (now Professor F. C. Frank of Bristol) and I looked at it and at one another and laughed; but since we had been set a silly problem we thought that we would deal with it in a suitable manner, and so we sent the collection of specimens to the chemical department at Farnborough for a formal analysis. We did not foresee the scare that was then to arise; Farnborough, instead of sending the report of their analysis directly back to us, sent it to the technical officers who were among the believers.

My Air Commodore friend telephoned me to say that

he now had the Farnborough report and that it substantiated the idea that the specimens had come from something quite mysterious, because one of them contained over 98% of an unknown chemical element. It was the grey porous specimen that was the cause of the trouble; Farnborough had analysed it for such elements as iron, manganese and so forth and had found traces of all of them adding up to less than 2%. The remaining 98% they had been unable to identify. Charles Frank and I were delighted. I telephoned the head of the chemical department at Farnborough (now a Fellow of the Royal Society) and asked him whether he really believed in the analysis that his Section had done. When he said that he did, I asked him how he could be satisfied with an analysis that left 98% of the substance unidentified, and he agreed that it was rather a puzzle. I then asked him whether they had tested for carbon. There was something of an explosion at the other end of the telephone. Carbon would not have shown up in any of the standard tests, but one had only to look at the material, as Charles Frank and I had done, to see that it was a lump of coke.

These were the only specimens that were ever claimed to have come from a Russian flying bomb, and the story might then have died. But by this time it had gone round the world and we received a signal from the British mission in Tokyo because General MacArthur had asked them to enquire into the story that a missile had fallen in England during the previous few weeks. The same Air Commodore telephoned me, asking how he should reply to the signal. I told him that, so far as I knew, nothing like a missile had fallen in England since the end of the war, and to this he replied: "Well, it might tie up with the Westerham incident." When I asked him what Westerham incident, he said: "Good God, I was supposed not to tell you about that." And then, of course, he had to tell me.

It transpired that on the previous Saturday one of my technical officers had received a telephone call from a man who said that his name was Gunyon, and that one of these newfangled contraptions had fallen out of the sky into one of his fields, and that he thought it was the Air Ministry's business to come and remove it. The technical officer concerned happened to be one of the believers and he saw a chance of convincing his Director that the Russian flying bomb really existed. He therefore asked farmer Gunyon how to find his farm, and was told that if one drove from Croydon to Westerham one should look out for a public house called 'The White Dog' and drive up the lane beside it, and that the farm was at the end of the lane. The technical intelligence resources of the Air Ministry were immediately mobilized and the two staff cars full of officers set off to find farmer Gunyon. When they got into the right area, they were disappointed to find no public house of the right name. But, being good Intelligence officers, they realized that the name may have been misheard over the telephone. They therefore enquired whether there were any public houses with similar names, and they were soon directed to one called 'The White Hart'. They were beginning, in any event, to need a drink, and they asked the publican whether he knew where farmer Gunyon lived. The pubkeeper did not know anyone by the name of Gunyon but, again, they asked whether he knew of anyone with a name that they could have mistaken for Gunyon over the telephone. Happily, he did. There was a farmer called Bunyan about three miles over the hill, and this astonished man duly received the full force of Air Technical Intelligence. Ultimately, he satisfied them that he had not telephoned the Air Ministry and that all his fields were in good order. They returned sadly to London. On the way, in seeking an explanation, they concluded that their Director had decided to have some fun with them and had made them waste their Saturday on a wild goose chase, just to teach them a lesson for their credulity. The only satisfaction left to them, they thought, was not to let their Director know how well he had succeeded, and they had therefore decided that they would not tell me what had happened. Although I appreciated their respect in giving me credit for such a happy hoax, I had in fact nothing to do with it, and I still do not know who thought of it. Even after that, some still believed in a Russian flying bomb, but the scare in Sweden and Britain gradually died down.

Even so, the Swedish scare had sensitized the western world so much that Kenneth Arnold's 1947 story set up a secondary scare in America that quickly overshadowed the primary source. Arnold was flying his own aircraft near Mt Ranier in Washington State on 24 June, when he saw "a chain of small saucer-like things at least five miles long swerving in and out of the high mountain peaks". There is no reason to doubt that Arnold genuinely saw something but, as D. H. Menzel has suggested, it may have been no more than snow swirling off the peaks or small clouds forming over them. Arnold's story triggered off a wave of sightings, with saucers appearing almost daily over one part or the other of the United States and since the Russians were at that time considered incapable of making apparitions cruise at such a long range, some other origin had to be found. The United States Air Force went even further than the Royal Air Force had done and set up an official investigation 'Project Saucer' on 22 January 1948 (this was succeeded in February 1949 by 'Project Grudge' and in March 1952 by 'Project Bluebook', which survives today). Eventually, in January 1953, a special Panel under CIA and USAF auspices was called to assess the evidence. The Chairman of the Panel was H. P. Robertson, the distinguished relativist, and with him were L. W. Alvarez, L. V. Berkner, S. A. Goudsmit and T. L. Page. They concluded, briefly, that there was no evidence for any "artefacts of a hostile foreign power", and that there should be a "debunking of the flying saucers".

The verdict of the Robertson Panel did much to restore a critical view of flying saucer stories and to offset the efforts of publicity seeking charlatans; but the Panel could not, of course, quell the enthusiasts who claimed to discern in its conclusions a range of motives that included the 'whitewashing' of the United States Air Force and its inability to cope with the invaders, celestial or otherwise (others even postulated that the unfortunate USAF had itself started the flying saucer stories by trying out a new secret weapon). If I may interject a personal comment here, it happens that I knew H. P. Robertson well; he was the representative appointed in 1943 by the American Chiefs of Staff to decide whether or not we in Britain were being hoaxed by the Germans regarding the existence of the V-1 flying bomb. He was immediately convinced by our evidence, and we owe him much, both for his personal help and for the promptness of the American technical support that followed his conclusion. He was always as anxious as anyone I know to establish the truth, and he would never have made an attempt to suppress it if it proved unpalatable; the same is true of the other members of his Panel who are known to me. Nevertheless, their findings have recently been criticized again, especially by a distinguished meteorologist, Dr James E. McDonald (1967) of the University of Arizona and by Dr J. Allen Hynek (1966), Director of the Dearborn Observatory of Northwestern University. Dr Hynek's criticism is the more interesting for the fact that he has been for 20 years a consultant to

the United States Air Force, and he was an associate member of the Robertson Panel. For most of this time he held that saucers were fictions, and he contributed an article to the *Encyclopaedia Britannica* (1964) that threw much doubt on their existence. Recently, however, he appears to have changed his mind, and he now believes that there are sufficient unexplained pieces of sound evidence to justify a new examination. As a result, the United States Air Force has set up a fresh investigation at the University of Colorado, Boulder, headed by Dr Edward Condon, the former Director of the National Bureau of Standards. The study was initiated in October 1966 and is expected to take 18 months at a cost of $300 000.

It appears that the Russians, too, have been facing similar doubts, for Air Force General Anatoli Stolyarov has recently been appointed head of a committee of investigation (*The Times*, 13 November 1967). Again, this comes some years after *Pravda* had published official denials of flying saucers in 1961.

Let us consider the difficulties that face these new investigations. Apart from the liars and hoaxers who have done much to confuse the issue, and those witnesses who have simply had hallucinations, there are many witnesses who have genuinely observed something. Some of these witnesses have seen manmade vehicles such as balloons, aircraft, rockets and satellites, but have misidentified them in unfamiliar circumstances. Others have seen natural phenomena including mirages, ice haloes, mock suns, Brocken ghosts, lenticular clouds, phosphorescence at sea, ball lightning, Venus and so forth. Some have seen and have even photographed convincing artefacts such as the detached image of the plane of a Herald aircraft through complex refraction at the edge of one of the cabin windows. Others have observed unusual echoes on radar screens such as the 'ring angels' due to the morning flight of starlings.

The foregoing explanations account for the majority of flying saucer reports. The size of the unexplained residue may be gauged from the statement of the Under Secretary of State for Defence in the House of Commons on 9 November 1967. Over the period 1 January 1959 to 30 September 1967, 625 reports were received by the Ministry of Defence; 70 remain unexplained after investigation. For comparison, the American figures, given by the Staff of Project Bluebook in a report of February 1966, are 6817 alleged sightings in the years 1953–65 inclusive; of these, 1248 were reported too vaguely to allow an attempt at explanation. Of the remaining 5569, there were 237 for which explanations could not be found.

Summarizing the British and American experience, it appears that perhaps 10% of the alleged sightings cannot be explained. In this residue, it is probable that the majority of witnesses have made substantial errors in their descriptions. A point of dispute is whether, after such errors have been allowed for, there is enough left that is unexplained to make us think that there is a gap in our knowledge either of natural phenomena or of an extraterrestial invasion of our atmosphere, perhaps by intelligently controlled spacecraft.

Those who have pressed the last explanation, and especially those who have believed in little men from Venus or Mars, must have been discouraged by the latest evidence regarding surface conditions on those planets. But I doubt whether they will be any more finally discouraged than were those who believed in the Russian flying bombs over Sweden. Hope is not the only thing that springs eternal in the human breast. If Earth proves to be the one planet in the solar system that supports intelligent life, it is still possible that intelligent beings from a more distant system have found the way to cross intervening space in small craft without ageing on the long journey; and, although it is unlikely, it is just possible that the craft are small enough not to have shown up on astronomical or radar surveys. Jesse Greenstein of Mt Wilson and Palomar Observatories has calculated that a vehicle 100 ft in diameter would easily show up at a height of 50 miles on any of the 5000 plates of the Palomar Sky Survey.

Perhaps I may be permitted to make some remarks on resolving the confusion of evidence, for I have had to do this before. In particular, I had to sort out the true from the false in the scare of 1943 about the threat of the German rocket. In the early stages this was not difficult, since there were few reports, and they were substantially secret and independent. But as the stories grew, it was almost impossible to tell whether or not a particular report came from someone who genuinely knew something or whether he was repeating a rumour. By that time there was no question about whether or not there was a rocket — the question was what it weighed. Finally I found a touchstone — I would accept a weight only from a report that had also mentioned that liquid oxygen was one of the fuels, which I by then knew to be true. The result was spectacular; out of hundreds of conflicting reports this touchstone selected only five, and these pointed consistently to a total weight of about 12 tons with a warhead from one to two tons, in contradistinction to the 80 tons with a 10 ton warhead that had been mooted. These five surviving reports thus led me to the correct answer.

Unfortunately, I have not found a similar touchstone for flying saucer reports. We are then left with assessing probabilities from what we know about the physical world, but we cannot reject the flying saucer hypothesis simply because it is unlikely. This would merely lead to the danger of repeating the error of the French Academy regarding meteorites. But are flying saucers simply of the first order of unlikeliness? I think not, for I would apply the same argument as I used regarding the apparitions in Sweden. There have been so many flying saucers seen by now, if we were to believe the accounts, that surely one of them must have broken down or left some trace of its visit. It is true that one can explain the absence of relics by supposing that the saucers have a fantastic reliability, but this adds another order of unlikeliness. At least the French Academy had some actual meteorites to examine.

I think that this is where the natural philosopher must take his stand, for there is a well tried course in such a situation. This is to apply 'Occam's razor' — hypotheses are not to be multiplied without necessity. Of all the possible explanations for a set of observations, the one with the minimum of supposition should be accepted, until it is proved wrong. Otherwise one lives in a fearsomely imaginative world in which rational conduct becomes impossible. There is a story of one of my more eccentric colleagues that will illustrate what I mean. He was at the time a Fellow of one of the men's colleges in Oxford, but he happened also to tutor some of the women students in philosophy. One of the girls went into his room for a tutorial one day, only to find that he seemed not to be there. However, she was accustomed to some of the curiosities in his behaviour and she was not unduly surprised when, a minute or two after she had sat down, his voice boomed from under the table: "Read your essay!" This she proceeded to do, and then waited for his comments. Something that she had said reminded him of Occam's razor and he proceeded to give her an example. Poking his head out from under the tablecloth he said:

"Supposing that I was to say to you that there is a tiger outside the door, but that the tiger is frightened of me so that every time I go to the door to see it, it runs away and hides round the corner. If I were to tell you that this was the explanation of why I see no tiger outside my door, you would say that I was mad — or, at least, a little peculiar!" Are flying saucers as imaginary as my colleague's tiger?

Of course, the difficulty in applying Occam's razor is in deciding which explanation of flying saucers involves the minimum hypothesis. Jefferson was committing scientific suicide with the razor when he preferred to believe that professors would lie. And it is also true that the explanation with the minimum of hypothesis is not always the right one. I can recall just one occasion when Occam led me astray in this way. This was towards the end of 1943 when the method of propulsion of the German flying bombs was unknown. I thought that I was able to deduce it from a set of facts as follows. On the plans of one of the flying bomb sites that had been sent to us by one of our spies, backed up by what we could see on aerial photographs, there seemed to be one fuel store on each site. Indeed, it was so labelled on the plan. The store was divided into two parts, and I concluded from the disposition of the entrances and blast walls that two kinds of fuel were to be used and that the designer was taking unusual precautions to prevent them from coming into contact. I already knew of two such fuels, hydrogen peroxide and sodium permanganate. These were already being used in rocket propelled glider bombs, and I even managed to establish that some of the servicing crews for these particular fuels were being allocated to the flying bomb sites. Moreover, when I checked the volume of peroxide that could be held in the store, it was enough to propel 20 peroxide rockets to London, and this was consistent with the storage in the rest of the site for 20 flying bomb bodies. There was therefore no need to postulate any other engine, on this evidence, for the flying bomb beyond a development of the peroxide rocket engine. Everything was consistent and had been well supported by evidence. And yet the conclusion was wrong. A more complicated hypothesis turned out to be right. The peroxide was used merely for firing the bombs from their catapults, and their main means of propulsion was a new type of engine, the Argus tube, which burned ordinary fuel. The reason that this ordinary fuel did not show up on the site was that the bombs arrived already filled with fuel from a central store.

At the same time, I must emphasize that in compensation for this one instance where Occam's razor led me astray, there were many instances where it led me to the truth when many other people were confused. The essential thing in applying the Razor is that one must be completely honest in realizing that, while it dictates the best operational course, it can lead to the wrong result and one must not cling to the simple explanation to which it leads if subsequent observations show that this is incorrect.

Here it is advisable to remember the advice of Pasteur (1854):

> Preconceived ideas are like searchlights which illumine the path of the experimenter and serve him as a guide to interrogate nature. They become a danger only if he transforms them into fixed ideas --- this is why I should like to see these profound words inscribed on the threshold of all the temples of science: 'The greatest derangement of the mind is to believe in something because one wishes it to be so.'

Keeping all these facts in mind, the balance of the evidence regarding flying saucers as I see it — viewed against the critical situations in which I used to have to decide on courses of action based on evidence from eye-witnesses and other sources — is heavily against their being intelligently controlled vehicles. But I also know that, even if the current American and Russian investigations come to this same conclusion or even a stronger one, it will not discourage the flying saucer believers. For these investigations are faced with the impossible job, if flying saucers do not exist, of proving a completely negative case. This is one of the most difficult of all Intelligence tasks, and even if the investigation is as thorough as humanly possible, the flying saucer exponents will always be able to conjure new hypotheses that had not been considered.

If known natural phenomena are insufficient to explain everything that has been genuinely seen, the alternative to the intelligently controlled vehicles is an as yet unrecognized natural phenomenon. This is distinctly possible — the case may be similar to that of ball lightning, the occurrence of which has long been both asserted and disputed. But ball lightning has been seen by many observers with a scientific training, including a Deputy Director of the Meteorological Office. In this it appears (apart from a few recent reports from Russia) to differ from the flying saucer and since there is no reason to expect that scientists are more likely to be favoured relatively to laymen by ball lightning than by flying saucers, we may conclude that either the saucers are much rarer even than the comparatively rare ball lightning, or that the latter has often been mistaken by lay observers for saucers.

In coming to a conclusion about the existence of flying saucers, there is a strong temptation to be overcautious, because if you turn out to be wrong in denying their existence the error will be blazoned in the history of science; but if you merely turn out to be right, there will be little credit in proving a negative case. My own position has been that if at any time in the last 20 years I had had to take a vital decision one way or the other according to whether I thought that flying saucers were fact or fantasy, Russian or extraterrestrial (why has China never been credited, by the way?), I would have taken that decision on the assumption that they were either a fantasy or an incorrect identification of a rare and unrecognized phenomenon; and while I commend any genuine search for new phenomena, little short of a tangible relic would dispel my scepticism of flying saucers.

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~~This~~ The report contains the results of a scientific inquiry into the phenomena of Unidentified Flying Objects. This volume (~~Volume III of 3 volumes~~) contains: (1) The Scientific Context, (2) Appendices A-X, and (3) The Index.

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